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(54) Title: ULTRASONIC ENERGY DEVICE WHICH VARIES PRESSURE APPLIED BY CLAMP ARM TO PROVIDE THRESHOLD CONTROL PRESSURE AT A CUT PROGRESSION LOCATION

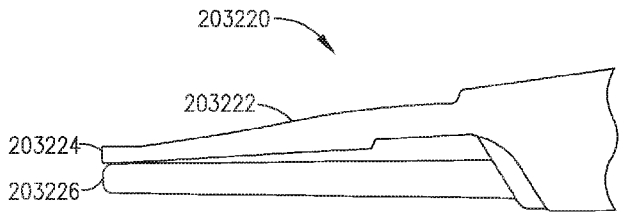


FIG. 30A

(57) Abstract: Surgical instruments and system and methods for using surgical instruments are disclosed. A surgical instrument comprises an end effector comprising an ultrasonic blade and clamp arm, an ultrasonic transducer, and a control circuit. The ultrasonic transducer ultrasonically oscillates the ultrasonic blade in response to a drive signal from a generator. The end effector receives electrosurgical energy to weld tissue. The control circuit determines a resonant frequency measure indicative of a thermally induced change in resonant frequency and a electrical continuity measure; calculates a weld focal point based on the determined measures, controls closure of the clamp arm to vary a pressure applied by the clamp arm to provide a threshold control pressure to the tissue loaded into the end effector, and maintains a gap between the ultrasonic blade and clamp arm at a point proximal to the proximal end of the tissue. Pressure is varied based on corresponding weld focal point.

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[Continued on next page]

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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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TITLE

ULTRASONIC ENERGY DEVICE WHICH VARIES PRESSURE APPLIED BY CLAMP ARM TO PROVIDE THRESHOLD CONTROL PRESSURE AT A CUT PROGRESSION LOCATION

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Non-Provisional Patent Application Serial No. 16/182,238, titled ULTRASONIC ENERGY DEVICE WHICH VARIES PRESSURE APPLIED BY CLAMP ARM TO PROVIDE THRESHOLD CONTROL PRESSURE AT A CUT PROGRESSION LOCATION, filed November 6, 2018, the disclosure of which is incorporated by reference herein it its entirety.

[0002] The present application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 62/729,195, titled ULTRASONIC ENERGY DEVICE WHICH VARIES PRESSURE APPLIED BY CLAMP ARM TO PROVIDE THRESHOLD CONTROL PRESSURE AT A CUT PROGRESSION LOCATION, filed on September 10, 2018, the disclosure of which is herein incorporated by reference in its entirety.

[0003] The present application also claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 62/692,747, titled SMART ACTIVATION OF AN ENERGY DEVICE BY ANOTHER DEVICE, filed on June 30, 2018, to U.S. Provisional Patent Application No. 62/692,748, titled SMART ENERGY ARCHITECTURE, filed on June 30, 2018, and to U.S. Provisional Patent Application No. 62/692,768, titled SMART ENERGY DEVICES, filed on June 30, 2018, the disclosure of each of which is herein incorporated by reference in its entirety.

[0004] The present application also claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 62/659,900, titled METHOD OF HUB COMMUNICATION, filed on April 19, 2018, the disclosure of each of which is herein incorporated by reference in its entirety.

[0005] The present application also claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 62/650,898 filed on March 30, 2018, titled CAPACITIVE COUPLED RETURN PATH PAD WITH SEPARABLE ARRAY ELEMENTS, to U.S. Provisional Patent Application Serial No. 62/650,887, titled SURGICAL SYSTEMS WITH OPTIMIZED SENSING CAPABILITIES, filed March 30, 2018, to U.S. Provisional Patent Application Serial No. 62/650,882, titled SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM, filed March 30, 2018, and to U.S. Provisional Patent Application Serial No. 62/650,877, titled SURGICAL SMOKE EVACUATION

SENSING AND CONTROLS, filed March 30, 2018, the disclosure of each of which is herein incorporated by reference in its entirety.

[0006] The present application also claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Serial No. 62/640,417, titled TEMPERATURE CONTROL IN ULTRASONIC DEVICE AND CONTROL SYSTEM THEREFOR, filed March 8, 2018, and to U.S. Provisional Patent Application Serial No. 62/640,415, titled ESTIMATING STATE OF ULTRASONIC END EFFECTOR AND CONTROL SYSTEM THEREFOR, filed March 8, 2018, the disclosure of each of which is herein incorporated by reference in its entirety.

[0007] The present application also claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, to U.S. Provisional Patent Application Serial No. 62/611,340, titled CLOUD-BASED MEDICAL ANALYTICS, filed December 28, 2017, and to U.S. Provisional Patent Application Serial No. 62/611,339, titled ROBOT ASSISTED SURGICAL PLATFORM, filed December 28, 2017, the disclosure of each of which is herein incorporated by reference in its entirety.

BACKGROUND

[0008] The present disclosure relates to various surgical systems. Surgical procedures are typically performed in surgical operating theaters or rooms in a healthcare facility such as, for example, a hospital. A sterile field is typically created around the patient. The sterile field may include the scrubbed team members, who are properly attired, and all furniture and fixtures in the area. Various surgical devices and systems are utilized in performance of a surgical procedure.

FIGURES

[0009] The various aspects described herein, both as to organization and methods of operation, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in conjunction with the accompanying drawings as follows.

[0010] FIG. 1 is a block diagram of a computer-implemented interactive surgical system, in accordance with at least one aspect of the present disclosure.

[0011] FIG. 2 is a surgical system being used to perform a surgical procedure in an operating room, in accordance with at least one aspect of the present disclosure.

[0012] FIG. 3 is a surgical hub paired with a visualization system, a robotic system, and an intelligent instrument, in accordance with at least one aspect of the present disclosure.

[0013] FIG. 4 is a partial perspective view of a surgical hub enclosure, and of a combo generator module slidably receivable in a drawer of the surgical hub enclosure, in accordance with at least one aspect of the present disclosure.

[0014] FIG. 5 is a perspective view of a combo generator module with bipolar, ultrasonic, and monopolar contacts and a smoke evacuation component, in accordance with at least one aspect of the present disclosure.

[0015] FIG. 6 illustrates individual power bus attachments for a plurality of lateral docking ports of a lateral modular housing configured to receive a plurality of modules, in accordance with at least one aspect of the present disclosure.

[0016] FIG. 7 illustrates a vertical modular housing configured to receive a plurality of modules, in accordance with at least one aspect of the present disclosure.

[0017] FIG. 8 illustrates a surgical data network comprising a modular communication hub configured to connect modular devices located in one or more operating theaters of a healthcare facility, or any room in a healthcare facility specially equipped for surgical operations, to the cloud, in accordance with at least one aspect of the present disclosure.

[0018] FIG. 9 illustrates a computer-implemented interactive surgical system, in accordance with at least one aspect of the present disclosure.

[0019] FIG. 10 illustrates a surgical hub comprising a plurality of modules coupled to the modular control tower, in accordance with at least one aspect of the present disclosure.

[0020] FIG. 11 illustrates one aspect of a Universal Serial Bus (USB) network hub device, in accordance with at least one aspect of the present disclosure.

[0021] FIG. 12 is a block diagram of a cloud computing system comprising a plurality of smart surgical instruments coupled to surgical hubs that may connect to the cloud component of the cloud computing system, in accordance with at least one aspect of the present disclosure.

[0022] FIG. 13 is a functional module architecture of a cloud computing system, in accordance with at least one aspect of the present disclosure.

[0023] FIG. 14 illustrates a diagram of a situationally aware surgical system, in accordance with at least one aspect of the present disclosure.

[0024] FIG. 15 is a timeline depicting situational awareness of a surgical hub, in accordance with at least one aspect of the present disclosure.

[0025] FIG. 16 is a schematic diagram of a robotic surgical instrument configured to operate a surgical tool described herein, in accordance with at least one aspect of the present disclosure.

[0026] FIG. 17 illustrates a block diagram of a surgical instrument programmed to control the distal translation of a displacement member, in accordance with at least one aspect of the present disclosure.

[0027] FIG. 18 is a schematic diagram of a surgical instrument configured to control various functions, in accordance with at least one aspect of the present disclosure.

[0028] FIG. 19 illustrates an example of a generator, in accordance with at least one aspect of the present disclosure.

[0029] FIG. 20 is a structural view of a generator architecture, in accordance with at least one aspect of the present disclosure.

[0030] FIG. 21 illustrates a generator circuit partitioned into multiple stages where a first stage circuit is common to the second stage circuit, in accordance with at least one aspect of the present disclosure.

[0031] FIG. 22 illustrates a diagram of one aspect of a surgical instrument comprising a feedback system for use with a surgical instrument, according to one aspect of the present disclosure.

[0032] FIG. 23A-23B are graphs including a graph of clamp force as a function of time and an associated graph of a coagulation/cut focal point, in accordance with at least one aspect of the present disclosure.

[0033] FIGS. 24A-24B are graphs including a graph of clamp force as a function of distance from the distal tip of the end effector and a graph of blade displacement as a function of distance from the distal tip, in accordance with at least one aspect of the present disclosure.

[0034] FIG. 25 is a graph of a clamp force distribution as a function of various sections along the length of the end effector, in accordance with at least one aspect of the present disclosure.

[0035] FIG. 26 is a graph of blade displacement profile as a function of distance from the distal tip of the end effector, in accordance with at least one aspect of the present disclosure.

[0036] FIGS. 27A-27C are sectional views of end effector that illustrate a closure stroke of the end effector, in accordance with at least one aspect of the present disclosure.

[0037] FIGS. 28A-28C are graphs of clamp force applied between the blade and clamp arm as a function of distance from the distal tip of the end effector corresponding to the sectional views of FIGS. 27A-27C, in accordance with at least one aspect of the present disclosure.

[0038] FIGS. 29A-29C are sectional views of the end effector that illustrate a proximal start closure stroke configuration, in accordance with at least one aspect of the present disclosure.

[0039] FIGS. 30A-30D are sectional views of the end effector that illustrate a distal start closure stroke configuration and indicate associated part stresses, in accordance with at least one aspect of the present disclosure.

[0040] FIGS. 31A-31D are graphs of clamp force applied between the ultrasonic blade and clamp arm as a function of distance from the distal tip of the end effector corresponding to

the sectional views of FIGS. 30A-30D, in accordance with at least one aspect of the present disclosure.

[0041] FIG. 32A-32E are sectional views of the end effector that illustrate a distal start closure stroke configuration and indicate associated part stresses, in accordance with at least one aspect of the present disclosure.

DESCRIPTION

[0042] Applicant of the present application owns the following U.S. Patent Applications, filed on November 6, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Patent Application No. 16/182,224, titled SURGICAL NETWORK, INSTRUMENT, AND CLOUD RESPONSES BASED ON VALIDATION OF RECEIVED DATASET AND AUTHENTICATION OF ITS SOURCE AND INTEGRITY;
- U.S. Patent Application No. 16/182,230, titled SURGICAL SYSTEM FOR PRESENTING INFORMATION INTERPRETED FROM EXTERNAL DATA;
- U.S. Patent Application No. 16/182,233, titled MODIFICATION OF SURGICAL SYSTEMS CONTROL PROGRAMS BASED ON MACHINE LEARNING;
- U.S. Patent Application No. 16/182,239, titled ADJUSTMENT OF DEVICE CONTROL PROGRAMS BASED ON STRATIFIED CONTEXTUAL DATA IN ADDITION TO THE DATA;
- U.S. Patent Application No. 16/182,243, titled SURGICAL HUB AND MODULAR DEVICE RESPONSE ADJUSTMENT BASED ON SITUATIONAL AWARENESS;
- U.S. Patent Application No. 16/182,248, titled DETECTION AND ESCALATION OF SECURITY RESPONSES OF SURGICAL INSTRUMENTS TO INCREASING SEVERITY THREATS;
- U.S. Patent Application No. 16/182,251, titled INTERACTIVE SURGICAL SYSTEM;
- U.S. Patent Application No. 16/182,260, titled AUTOMATED DATA SCALING, ALIGNMENT, AND ORGANIZING BASED ON PREDEFINED PARAMETERS WITHIN SURGICAL NETWORKS;
- U.S. Patent Application No. 16/182,267, titled SENSING THE PATIENT POSITION AND CONTACT UTILIZING THE MONO-POLAR RETURN PAD ELECTRODE TO PROVIDE SITUATIONAL AWARENESS TO A SURGICAL NETWORK;
- U.S. Patent Application No. 16/182,249, titled POWERED SURGICAL TOOL WITH PREDEFINED ADJUSTABLE CONTROL ALGORITHM FOR CONTROLLING END EFFECTOR PARAMETER;

- U.S. Patent Application No. 16/182,246, titled ADJUSTMENTS BASED ON AIRBORNE PARTICLE PROPERTIES;
- U.S. Patent Application No. 16/182,256, titled ADJUSTMENT OF A SURGICAL DEVICE FUNCTION BASED ON SITUATIONAL AWARENESS;
- U.S. Patent Application No. 16/182,242, titled REAL-TIME ANALYSIS OF COMPREHENSIVE COST OF ALL INSTRUMENTATION USED IN SURGERY UTILIZING DATA FLUIDITY TO TRACK INSTRUMENTS THROUGH STOCKING AND IN-HOUSE PROCESSES;
- U.S. Patent Application No. 16/182,255, titled USAGE AND TECHNIQUE ANALYSIS OF SURGEON / STAFF PERFORMANCE AGAINST A BASELINE TO OPTIMIZE DEVICE UTILIZATION AND PERFORMANCE FOR BOTH CURRENT AND FUTURE PROCEDURES;
- U.S. Patent Application No. 16/182,269, titled IMAGE CAPTURING OF THE AREAS OUTSIDE THE ABDOMEN TO IMPROVE PLACEMENT AND CONTROL OF A SURGICAL DEVICE IN USE;
- U.S. Patent Application No. 16/182,278, titled COMMUNICATION OF DATA WHERE A SURGICAL NETWORK IS USING CONTEXT OF THE DATA AND REQUIREMENTS OF A RECEIVING SYSTEM / USER TO INFLUENCE INCLUSION OR LINKAGE OF DATA AND METADATA TO ESTABLISH CONTINUITY;
- U.S. Patent Application No. 16/182,290, titled SURGICAL NETWORK RECOMMENDATIONS FROM REAL TIME ANALYSIS OF PROCEDURE VARIABLES AGAINST A BASELINE HIGHLIGHTING DIFFERENCES FROM THE OPTIMAL SOLUTION;
- U.S. Patent Application No. 16/182,232, titled CONTROL OF A SURGICAL SYSTEM THROUGH A SURGICAL BARRIER;
- U.S. Patent Application No. 16/182,227, titled SURGICAL NETWORK DETERMINATION OF PRIORITIZATION OF COMMUNICATION, INTERACTION, OR PROCESSING BASED ON SYSTEM OR DEVICE NEEDS;
- U.S. Patent Application No. 16/182,231, titled WIRELESS PAIRING OF A SURGICAL DEVICE WITH ANOTHER DEVICE WITHIN A STERILE SURGICAL FIELD BASED ON THE USAGE AND SITUATIONAL AWARENESS OF DEVICES;
- U.S. Patent Application No. 16/182,229, titled ADJUSTMENT OF STAPLE HEIGHT OF AT LEAST ONE ROW OF STAPLES BASED ON THE SENSED TISSUE THICKNESS OR FORCE IN CLOSING;

- U.S. Patent Application No. 16/182,234, titled STAPLING DEVICE WITH BOTH COMPULSORY AND DISCRETIONARY LOCKOUTS BASED ON SENSED PARAMETERS;
- U.S. Patent Application No. 16/182,240, titled POWERED STAPLING DEVICE CONFIGURED TO ADJUST FORCE, ADVANCEMENT SPEED, AND OVERALL STROKE OF CUTTING MEMBER BASED ON SENSED PARAMETER OF FIRING OR CLAMPING; and
- U.S. Patent Application No. 16/182,235, titled VARIATION OF RADIO FREQUENCY AND ULTRASONIC POWER LEVEL IN COOPERATION WITH VARYING CLAMP ARM PRESSURE TO ACHIEVE PREDEFINED HEAT FLUX OR POWER APPLIED TO TISSUE.

[0043] Applicant of the present application owns the following U.S. Patent Applications, filed on September 10, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application No. 62/729,183, titled A CONTROL FOR A SURGICAL NETWORK OR SURGICAL NETWORK CONNECTED DEVICE THAT ADJUSTS ITS FUNCTION BASED ON A SENSED SITUATION OR USAGE;
- U.S. Provisional Patent Application No. 62/729,177, titled AUTOMATED DATA SCALING, ALIGNMENT, AND ORGANIZING BASED ON PREDEFINED PARAMETERS WITHIN A SURGICAL NETWORK BEFORE TRANSMISSION;
- U.S. Provisional Patent Application No. 62/729,176, titled INDIRECT COMMAND AND CONTROL OF A FIRST OPERATING ROOM SYSTEM THROUGH THE USE OF A SECOND OPERATING ROOM SYSTEM WITHIN A STERILE FIELD WHERE THE SECOND OPERATING ROOM SYSTEM HAS PRIMARY AND SECONDARY OPERATING MODES;
- U.S. Provisional Patent Application No. 62/729,185, titled POWERED STAPLING DEVICE THAT IS CAPABLE OF ADJUSTING FORCE, ADVANCEMENT SPEED, AND OVERALL STROKE OF CUTTING MEMBER OF THE DEVICE BASED ON SENSED PARAMETER OF FIRING OR CLAMPING;
- U.S. Provisional Patent Application No. 62/729,184, titled POWERED SURGICAL TOOL WITH A PREDEFINED ADJUSTABLE CONTROL ALGORITHM FOR CONTROLLING AT LEAST ONE END EFFECTOR PARAMETER AND A MEANS FOR LIMITING THE ADJUSTMENT;
- U.S. Provisional Patent Application No. 62/729,182, titled SENSING THE PATIENT POSITION AND CONTACT UTILIZING THE MONO POLAR RETURN PAD ELECTRODE TO PROVIDE SITUATIONAL AWARENESS TO THE HUB;

- U.S. Provisional Patent Application No. 62/729,191, titled SURGICAL NETWORK RECOMMENDATIONS FROM REAL TIME ANALYSIS OF PROCEDURE VARIABLES AGAINST A BASELINE HIGHLIGHTING DIFFERENCES FROM THE OPTIMAL SOLUTION;
- U.S. Provisional Patent Application No. 62/729,195, titled ULTRASONIC ENERGY DEVICE WHICH VARIES PRESSURE APPLIED BY CLAMP ARM TO PROVIDE THRESHOLD CONTROL PRESSURE AT A CUT PROGRESSION LOCATION; and
- U.S. Provisional Patent Application No. 62/729,186, titled WIRELESS PAIRING OF A SURGICAL DEVICE WITH ANOTHER DEVICE WITHIN A STERILE SURGICAL FIELD BASED ON THE USAGE AND SITUATIONAL AWARENESS OF DEVICES.

[0044] Applicant of the present application owns the following U.S. Patent Applications, filed on August 28, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Patent Application No. 16/115,214, titled ESTIMATING STATE OF ULTRASONIC END EFFECTOR AND CONTROL SYSTEM THEREFOR;
- U.S. Patent Application No. 16/115,205, titled TEMPERATURE CONTROL OF ULTRASONIC END EFFECTOR AND CONTROL SYSTEM THEREFOR;
- U.S. Patent Application No. 16/115,233, titled RADIO FREQUENCY ENERGY DEVICE FOR DELIVERING COMBINED ELECTRICAL SIGNALS;
- U.S. Patent Application No. 16/115,208, titled CONTROLLING AN ULTRASONIC SURGICAL INSTRUMENT ACCORDING TO TISSUE LOCATION;
- U.S. Patent Application No. 16/115,220, titled CONTROLLING ACTIVATION OF AN ULTRASONIC SURGICAL INSTRUMENT ACCORDING TO THE PRESENCE OF TISSUE;
- U.S. Patent Application No. 16/115,232, titled DETERMINING TISSUE COMPOSITION VIA AN ULTRASONIC SYSTEM;
- U.S. Patent Application No. 16/115,239, titled DETERMINING THE STATE OF AN ULTRASONIC ELECTROMECHANICAL SYSTEM ACCORDING TO FREQUENCY SHIFT;
- U.S. Patent Application No. 16/115,247, titled DETERMINING THE STATE OF AN ULTRASONIC END EFFECTOR;
- U.S. Patent Application No. 16/115,211, titled SITUATIONAL AWARENESS OF ELECTROSURGICAL SYSTEMS;
- U.S. Patent Application No. 16/115,226, titled MECHANISMS FOR CONTROLLING DIFFERENT ELECTROMECHANICAL SYSTEMS OF AN ELECTROSURGICAL INSTRUMENT;

- U.S. Patent Application No. 16/115,240, titled DETECTION OF END EFFECTOR IMMERSION IN LIQUID;
- U.S. Patent Application No. 16/115,249, titled INTERRUPTION OF ENERGY DUE TO INADVERTENT CAPACITIVE COUPLING;
- U.S. Patent Application No. 16/115,256, titled INCREASING RADIO FREQUENCY TO CREATE PAD-LESS MONOPOLAR LOOP;
- U.S. Patent Application No. 16/115,223, titled BIPOLAR COMBINATION DEVICE THAT AUTOMATICALLY ADJUSTS PRESSURE BASED ON ENERGY MODALITY; and
- U.S. Patent Application No. 16/115,238, titled ACTIVATION OF ENERGY DEVICES.

[0045] Applicant of the present application owns the following U.S. Patent Applications, filed on August 23, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application No. 62/721,995, titled CONTROLLING AN ULTRASONIC SURGICAL INSTRUMENT ACCORDING TO TISSUE LOCATION;
- U.S. Provisional Patent Application No. 62/721,998, titled SITUATIONAL AWARENESS OF ELECTROSURGICAL SYSTEMS;
- U.S. Provisional Patent Application No. 62/721,999, titled INTERRUPTION OF ENERGY DUE TO INADVERTENT CAPACITIVE COUPLING;
- U.S. Provisional Patent Application No. 62/721,994, titled BIPOLAR COMBINATION DEVICE THAT AUTOMATICALLY ADJUSTS PRESSURE BASED ON ENERGY MODALITY; and
- U.S. Provisional Patent Application No. 62/721,996, titled RADIO FREQUENCY ENERGY DEVICE FOR DELIVERING COMBINED ELECTRICAL SIGNALS.

[0046] Applicant of the present application owns the following U.S. Patent Applications, filed on June 30, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application No. 62/692,747, titled SMART ACTIVATION OF AN ENERGY DEVICE BY ANOTHER DEVICE;
- U.S. Provisional Patent Application No. 62/692,748, titled SMART ENERGY ARCHITECTURE; and
- U.S. Provisional Patent Application No. 62/692,768, titled SMART ENERGY DEVICES.

[0047] Applicant of the present application owns the following U.S. Patent Applications, filed on June 29, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Patent Application Serial No. 16/024,090, titled CAPACITIVE COUPLED RETURN PATH PAD WITH SEPARABLE ARRAY ELEMENTS;
- U.S. Patent Application Serial No. 16/024,057, titled CONTROLLING A SURGICAL INSTRUMENT ACCORDING TO SENSED CLOSURE PARAMETERS;
- U.S. Patent Application Serial No. 16/024,067, titled SYSTEMS FOR ADJUSTING END EFFECTOR PARAMETERS BASED ON PERIOPERATIVE INFORMATION;
- U.S. Patent Application Serial No. 16/024,075, titled SAFETY SYSTEMS FOR SMART POWERED SURGICAL STAPLING;
- U.S. Patent Application Serial No. 16/024,083, titled SAFETY SYSTEMS FOR SMART POWERED SURGICAL STAPLING;
- U.S. Patent Application Serial No. 16/024,094, titled SURGICAL SYSTEMS FOR DETECTING END EFFECTOR TISSUE DISTRIBUTION IRREGULARITIES;
- U.S. Patent Application Serial No. 16/024,138, titled SYSTEMS FOR DETECTING PROXIMITY OF SURGICAL END EFFECTOR TO CANCEROUS TISSUE;
- U.S. Patent Application Serial No. 16/024,150, titled SURGICAL INSTRUMENT CARTRIDGE SENSOR ASSEMBLIES;
- U.S. Patent Application Serial No. 16/024,160, titled VARIABLE OUTPUT CARTRIDGE SENSOR ASSEMBLY;
- U.S. Patent Application Serial No. 16/024,124, titled SURGICAL INSTRUMENT HAVING A FLEXIBLE ELECTRODE;
- U.S. Patent Application Serial No. 16/024,132, titled SURGICAL INSTRUMENT HAVING A FLEXIBLE CIRCUIT;
- U.S. Patent Application Serial No. 16/024,141, titled SURGICAL INSTRUMENT WITH A TISSUE MARKING ASSEMBLY;
- U.S. Patent Application Serial No. 16/024,162, titled SURGICAL SYSTEMS WITH PRIORITIZED DATA TRANSMISSION CAPABILITIES;
- U.S. Patent Application Serial No. 16/024,066, titled SURGICAL EVACUATION SENSING AND MOTOR CONTROL;
- U.S. Patent Application Serial No. 16/024,096, titled SURGICAL EVACUATION SENSOR ARRANGEMENTS;
- U.S. Patent Application Serial No. 16/024,116, titled SURGICAL EVACUATION FLOW PATHS;
- U.S. Patent Application Serial No. 16/024,149, titled SURGICAL EVACUATION SENSING AND GENERATOR CONTROL;
- U.S. Patent Application Serial No. 16/024,180, titled SURGICAL EVACUATION SENSING AND DISPLAY;

- U.S. Patent Application Serial No. 16/024,245, titled COMMUNICATION OF SMOKE EVACUATION SYSTEM PARAMETERS TO HUB OR CLOUD IN SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM;
- U.S. Patent Application Serial No. 16/024,258, titled SMOKE EVACUATION SYSTEM INCLUDING A SEGMENTED CONTROL CIRCUIT FOR INTERACTIVE SURGICAL PLATFORM;
- U.S. Patent Application Serial No. 16/024,265, titled SURGICAL EVACUATION SYSTEM WITH A COMMUNICATION CIRCUIT FOR COMMUNICATION BETWEEN A FILTER AND A SMOKE EVACUATION DEVICE; and
- U.S. Patent Application Serial No. 16/024,273, titled DUAL IN-SERIES LARGE AND SMALL DROPLET FILTERS.

[0048] Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on June 28, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. 62/691,228, titled A METHOD OF USING REINFORCED FLEX CIRCUITS WITH MULTIPLE SENSORS WITH ELECTROSURGICAL DEVICES;
- U.S. Provisional Patent Application Serial No. 62/691,227, titled CONTROLLING A SURGICAL INSTRUMENT ACCORDING TO SENSED CLOSURE PARAMETERS;
- U.S. Provisional Patent Application Serial No. 62/691,230, titled SURGICAL INSTRUMENT HAVING A FLEXIBLE ELECTRODE;
- U.S. Provisional Patent Application Serial No. 62/691,219, titled SURGICAL EVACUATION SENSING AND MOTOR CONTROL;
- U.S. Provisional Patent Application Serial No. 62/691,257, titled COMMUNICATION OF SMOKE EVACUATION SYSTEM PARAMETERS TO HUB OR CLOUD IN SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM;
- U.S. Provisional Patent Application Serial No. 62/691,262, titled SURGICAL EVACUATION SYSTEM WITH A COMMUNICATION CIRCUIT FOR COMMUNICATION BETWEEN A FILTER AND A SMOKE EVACUATION DEVICE; and
- U.S. Provisional Patent Application Serial No. 62/691,251, titled DUAL IN-SERIES LARGE AND SMALL DROPLET FILTERS.

[0049] Applicant of the present application owns the following U.S. Provisional Patent Application, filed on April 19, 2018, the disclosure of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. 62/659,900, titled METHOD OF HUB COMMUNICATION.

[0050] Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on March 30, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application No. 62/650,898 filed on March 30, 2018, titled CAPACITIVE COUPLED RETURN PATH PAD WITH SEPARABLE ARRAY ELEMENTS;
- U.S. Provisional Patent Application Serial No. 62/650,887, titled SURGICAL SYSTEMS WITH OPTIMIZED SENSING CAPABILITIES;
- U.S. Provisional Patent Application Serial No. 62/650,882, titled SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM; and
- U.S. Provisional Patent Application Serial No. 62/650,877, titled SURGICAL SMOKE EVACUATION SENSING AND CONTROLS.

[0051] Applicant of the present application owns the following U.S. Patent Applications, filed on March 29, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Patent Application Serial No. 15/940,641, titled INTERACTIVE SURGICAL SYSTEMS WITH ENCRYPTED COMMUNICATION CAPABILITIES;
- U.S. Patent Application Serial No. 15/940,648, titled INTERACTIVE SURGICAL SYSTEMS WITH CONDITION HANDLING OF DEVICES AND DATA CAPABILITIES;
- U.S. Patent Application Serial No. 15/940,656, titled SURGICAL HUB COORDINATION OF CONTROL AND COMMUNICATION OF OPERATING ROOM DEVICES;
- U.S. Patent Application Serial No. 15/940,666, titled SPATIAL AWARENESS OF SURGICAL HUBS IN OPERATING ROOMS;
- U.S. Patent Application Serial No. 15/940,670, titled COOPERATIVE UTILIZATION OF DATA DERIVED FROM SECONDARY SOURCES BY INTELLIGENT SURGICAL HUBS;
- U.S. Patent Application Serial No. 15/940,677, titled SURGICAL HUB CONTROL ARRANGEMENTS;
- U.S. Patent Application Serial No. 15/940,632, titled DATA STRIPPING METHOD TO INTERROGATE PATIENT RECORDS AND CREATE ANONYMIZED RECORD;
- U.S. Patent Application Serial No. 15/940,640, titled COMMUNICATION HUB AND STORAGE DEVICE FOR STORING PARAMETERS AND STATUS OF A

SURGICAL DEVICE TO BE SHARED WITH CLOUD BASED ANALYTICS SYSTEMS;

- U.S. Patent Application Serial No. 15/940,645, titled SELF DESCRIBING DATA PACKETS GENERATED AT AN ISSUING INSTRUMENT;
- U.S. Patent Application Serial No. 15/940,649, titled DATA PAIRING TO INTERCONNECT A DEVICE MEASURED PARAMETER WITH AN OUTCOME;
- U.S. Patent Application Serial No. 15/940,654, titled SURGICAL HUB SITUATIONAL AWARENESS;
- U.S. Patent Application Serial No. 15/940,663, titled SURGICAL SYSTEM DISTRIBUTED PROCESSING;
- U.S. Patent Application Serial No. 15/940,668, titled AGGREGATION AND REPORTING OF SURGICAL HUB DATA;
- U.S. Patent Application Serial No. 15/940,671, titled SURGICAL HUB SPATIAL AWARENESS TO DETERMINE DEVICES IN OPERATING THEATER;
- U.S. Patent Application Serial No. 15/940,686, titled DISPLAY OF ALIGNMENT OF STAPLE CARTRIDGE TO PRIOR LINEAR STAPLE LINE;
- U.S. Patent Application Serial No. 15/940,700, titled STERILE FIELD INTERACTIVE CONTROL DISPLAYS;
- U.S. Patent Application Serial No. 15/940,629, titled COMPUTER IMPLEMENTED INTERACTIVE SURGICAL SYSTEMS;
- U.S. Patent Application Serial No. 15/940,704, titled USE OF LASER LIGHT AND RED-GREEN-BLUE COLORATION TO DETERMINE PROPERTIES OF BACK SCATTERED LIGHT;
- U.S. Patent Application Serial No. 15/940,722, titled CHARACTERIZATION OF TISSUE IRREGULARITIES THROUGH THE USE OF MONO-CHROMATIC LIGHT REFRACTIVITY;
- U.S. Patent Application Serial No. 15/940,742, titled DUAL CMOS ARRAY IMAGING;
- U.S. Patent Application Serial No. 15/940,636, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL DEVICES;
- U.S. Patent Application Serial No. 15/940,653, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL HUBS;
- U.S. Patent Application Serial No. 15/940,660, titled CLOUD-BASED MEDICAL ANALYTICS FOR CUSTOMIZATION AND RECOMMENDATIONS TO A USER;
- U.S. Patent Application Serial No. 15/940,679, titled CLOUD-BASED MEDICAL ANALYTICS FOR LINKING OF LOCAL USAGE TRENDS WITH THE RESOURCE ACQUISITION BEHAVIORS OF LARGER DATA SET;

- U.S. Patent Application Serial No. 15/940,694, titled CLOUD-BASED MEDICAL ANALYTICS FOR MEDICAL FACILITY SEGMENTED INDIVIDUALIZATION OF INSTRUMENT FUNCTION;
- U.S. Patent Application Serial No. 15/940,634, titled CLOUD-BASED MEDICAL ANALYTICS FOR SECURITY AND AUTHENTICATION TRENDS AND REACTIVE MEASURES;
- U.S. Patent Application Serial No. 15/940,706, titled DATA HANDLING AND PRIORITIZATION IN A CLOUD ANALYTICS NETWORK;
- U.S. Patent Application Serial No. 15/940,675, titled CLOUD INTERFACE FOR COUPLED SURGICAL DEVICES;
- U.S. Patent Application Serial No. 15/940,627, titled DRIVE ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,637, titled COMMUNICATION ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,642, titled CONTROLS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,676, titled AUTOMATIC TOOL ADJUSTMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,680, titled CONTROLLERS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,683, titled COOPERATIVE SURGICAL ACTIONS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,690, titled DISPLAY ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; and
- U.S. Patent Application Serial No. 15/940,711, titled SENSING ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS.

[0052] Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on March 28, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. 62/649,302, titled INTERACTIVE SURGICAL SYSTEMS WITH ENCRYPTED COMMUNICATION CAPABILITIES;
- U.S. Provisional Patent Application Serial No. 62/649,294, titled DATA STRIPPING METHOD TO INTERROGATE PATIENT RECORDS AND CREATE ANONYMIZED RECORD;
- U.S. Provisional Patent Application Serial No. 62/649,300, titled SURGICAL HUB SITUATIONAL AWARENESS;

- U.S. Provisional Patent Application Serial No. 62/649,309, titled SURGICAL HUB SPATIAL AWARENESS TO DETERMINE DEVICES IN OPERATING THEATER;
- U.S. Provisional Patent Application Serial No. 62/649,310, titled COMPUTER IMPLEMENTED INTERACTIVE SURGICAL SYSTEMS;
- U.S. Provisional Patent Application Serial No. 62/649,291, titled USE OF LASER LIGHT AND RED-GREEN-BLUE COLORATION TO DETERMINE PROPERTIES OF BACK SCATTERED LIGHT;
- U.S. Provisional Patent Application Serial No. 62/649,296, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL DEVICES;
- U.S. Provisional Patent Application Serial No. 62/649,333, titled CLOUD-BASED MEDICAL ANALYTICS FOR CUSTOMIZATION AND RECOMMENDATIONS TO A USER;
- U.S. Provisional Patent Application Serial No. 62/649,327, titled CLOUD-BASED MEDICAL ANALYTICS FOR SECURITY AND AUTHENTICATION TRENDS AND REACTIVE MEASURES;
- U.S. Provisional Patent Application Serial No. 62/649,315, titled DATA HANDLING AND PRIORITIZATION IN A CLOUD ANALYTICS NETWORK;
- U.S. Provisional Patent Application Serial No. 62/649,313, titled CLOUD INTERFACE FOR COUPLED SURGICAL DEVICES;
- U.S. Provisional Patent Application Serial No. 62/649,320, titled DRIVE ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Provisional Patent Application Serial No. 62/649,307, titled AUTOMATIC TOOL ADJUSTMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; and
- U.S. Provisional Patent Application Serial No. 62/649,323, titled SENSING ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS.

[0053] Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on March 8, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. 62/640,417, titled TEMPERATURE CONTROL IN ULTRASONIC DEVICE AND CONTROL SYSTEM THEREFOR; and
- U.S. Provisional Patent Application Serial No. 62/640,415, titled ESTIMATING STATE OF ULTRASONIC END EFFECTOR AND CONTROL SYSTEM THEREFOR.

[0054] Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on December 28, 2017, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM;
- U.S. Provisional Patent Application Serial No. 62/611,340, titled CLOUD-BASED MEDICAL ANALYTICS; and
- U.S. Provisional Patent Application Serial No. 62/611,339, titled ROBOT ASSISTED SURGICAL PLATFORM.

[0055] Before explaining various aspects of surgical devices and generators in detail, it should be noted that the illustrative examples are not limited in application or use to the details of construction and arrangement of parts illustrated in the accompanying drawings and description. The illustrative examples may be implemented or incorporated in other aspects, variations and modifications, and may be practiced or carried out in various ways. Further, unless otherwise indicated, the terms and expressions employed herein have been chosen for the purpose of describing the illustrative examples for the convenience of the reader and are not for the purpose of limitation thereof. Also, it will be appreciated that one or more of the following-described aspects, expressions of aspects, and/or examples, can be combined with any one or more of the other following-described aspects, expressions of aspects and/or examples.

Surgical Hubs

[0056] Referring to FIG. 1, a computer-implemented interactive surgical system 100 includes one or more surgical systems 102 and a cloud-based system (e.g., the cloud 104 that may include a remote server 113 coupled to a storage device 105). Each surgical system 102 includes at least one surgical hub 106 in communication with the cloud 104 that may include a remote server 113. In one example, as illustrated in FIG. 1, the surgical system 102 includes a visualization system 108, a robotic system 110, and a handheld intelligent surgical instrument 112, which are configured to communicate with one another and/or the hub 106. In some aspects, a surgical system 102 may include an M number of hubs 106, an N number of visualization systems 108, an O number of robotic systems 110, and a P number of handheld intelligent surgical instruments 112, where M, N, O, and P are integers greater than or equal to one.

[0057] In various aspects, the intelligent instruments 112 as described herein with reference to FIGS. 1-7 may be implemented as ultrasonic surgical instruments and combination energy surgical instruments 7012 as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E. The intelligent instruments 112 (e.g., devices 1a-1n) such as ultrasonic/combination surgical instruments 7012 as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-

31D, 32A-32E are configured to operate in a surgical data network 201 as described with reference to FIG. 8.

[0058] FIG. 2 depicts an example of a surgical system 102 being used to perform a surgical procedure on a patient who is lying down on an operating table 114 in a surgical operating room 116. A robotic system 110 is used in the surgical procedure as a part of the surgical system 102. The robotic system 110 includes a surgeon's console 118, a patient side cart 120 (surgical robot), and a surgical robotic hub 122. The patient side cart 120 can manipulate at least one removably coupled surgical tool 117 through a minimally invasive incision in the body of the patient while the surgeon views the surgical site through the surgeon's console 118. An image of the surgical site can be obtained by a medical imaging device 124, which can be manipulated by the patient side cart 120 to orient the imaging device 124. The robotic hub 122 can be used to process the images of the surgical site for subsequent display to the surgeon through the surgeon's console 118.

[0059] Other types of robotic systems can be readily adapted for use with the surgical system 102. Various examples of robotic systems and surgical tools that are suitable for use with the present disclosure are described in U.S. Provisional Patent Application Serial No. 62/611,339, titled ROBOT ASSISTED SURGICAL PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

[0060] Various examples of cloud-based analytics that are performed by the cloud 104, and are suitable for use with the present disclosure, are described in U.S. Provisional Patent Application Serial No. 62/611,340, titled CLOUD-BASED MEDICAL ANALYTICS, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

[0061] In various aspects, the imaging device 124 includes at least one image sensor and one or more optical components. Suitable image sensors include, but are not limited to, Charge-Coupled Device (CCD) sensors and Complementary Metal-Oxide Semiconductor (CMOS) sensors.

[0062] The optical components of the imaging device 124 may include one or more illumination sources and/or one or more lenses. The one or more illumination sources may be directed to illuminate portions of the surgical field. The one or more image sensors may receive light reflected or refracted from the surgical field, including light reflected or refracted from tissue and/or surgical instruments.

[0063] The one or more illumination sources may be configured to radiate electromagnetic energy in the visible spectrum as well as the invisible spectrum. The visible spectrum, sometimes referred to as the optical spectrum or luminous spectrum, is that portion of the electromagnetic spectrum that is visible to (i.e., can be detected by) the human eye and may

be referred to as visible light or simply light. A typical human eye will respond to wavelengths in air that are from about 380 nm to about 750 nm.

[0064] The invisible spectrum (i.e., the non-luminous spectrum) is that portion of the electromagnetic spectrum that lies below and above the visible spectrum (i.e., wavelengths below about 380 nm and above about 750 nm). The invisible spectrum is not detectable by the human eye. Wavelengths greater than about 750 nm are longer than the red visible spectrum, and they become invisible infrared (IR), microwave, and radio electromagnetic radiation. Wavelengths less than about 380 nm are shorter than the violet spectrum, and they become invisible ultraviolet, x-ray, and gamma ray electromagnetic radiation.

[0065] In various aspects, the imaging device 124 is configured for use in a minimally invasive procedure. Examples of imaging devices suitable for use with the present disclosure include, but not limited to, an arthroscope, angioscope, bronchoscope, choledochoscope, colonoscope, cytoscope, duodenoscope, enteroscope, esophagogastro-duodenoscope (gastroscope), endoscope, laryngoscope, nasopharyngo-neproscope, sigmoidoscope, thoracoscope, and ureteroscope.

[0066] In one aspect, the imaging device employs multi-spectrum monitoring to discriminate topography and underlying structures. A multi-spectral image is one that captures image data within specific wavelength ranges across the electromagnetic spectrum. The wavelengths may be separated by filters or by the use of instruments that are sensitive to particular wavelengths, including light from frequencies beyond the visible light range, e.g., IR and ultraviolet. Spectral imaging can allow extraction of additional information the human eye fails to capture with its receptors for red, green, and blue. The use of multi-spectral imaging is described in greater detail under the heading "Advanced Imaging Acquisition Module" in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety. Multi-spectrum monitoring can be a useful tool in relocating a surgical field after a surgical task is completed to perform one or more of the previously described tests on the treated tissue.

[0067] It is axiomatic that strict sterilization of the operating room and surgical equipment is required during any surgery. The strict hygiene and sterilization conditions required in a "surgical theater," i.e., an operating or treatment room, necessitate the highest possible sterility of all medical devices and equipment. Part of that sterilization process is the need to sterilize anything that comes in contact with the patient or penetrates the sterile field, including the imaging device 124 and its attachments and components. It will be appreciated that the sterile field may be considered a specified area, such as within a tray or on a sterile towel, that is considered free of microorganisms, or the sterile field may be considered an area, immediately around a patient, who has been prepared for a surgical procedure. The

sterile field may include the scrubbed team members, who are properly attired, and all furniture and fixtures in the area.

[0068] In various aspects, the visualization system 108 includes one or more imaging sensors, one or more image-processing units, one or more storage arrays, and one or more displays that are strategically arranged with respect to the sterile field, as illustrated in FIG. 2. In one aspect, the visualization system 108 includes an interface for HL7, PACS, and EMR. Various components of the visualization system 108 are described under the heading "Advanced Imaging Acquisition Module" in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

[0069] As illustrated in FIG. 2, a primary display 119 is positioned in the sterile field to be visible to an operator at the operating table 114. In addition, a visualization tower 111 is positioned outside the sterile field. The visualization tower 111 includes a first non-sterile display 107 and a second non-sterile display 109, which face away from each other. The visualization system 108, guided by the hub 106, is configured to utilize the displays 107, 109, and 119 to coordinate information flow to operators inside and outside the sterile field. For example, the hub 106 may cause the visualization system 108 to display a snapshot of a surgical site, as recorded by an imaging device 124, on a non-sterile display 107 or 109, while maintaining a live feed of the surgical site on the primary display 119. The snapshot on the non-sterile display 107 or 109 can permit a non-sterile operator to perform a diagnostic step relevant to the surgical procedure, for example.

[0070] In one aspect, the hub 106 is also configured to route a diagnostic input or feedback entered by a non-sterile operator at the visualization tower 111 to the primary display 119 within the sterile field, where it can be viewed by a sterile operator at the operating table. In one example, the input can be in the form of a modification to the snapshot displayed on the non-sterile display 107 or 109, which can be routed to the primary display 119 by the hub 106.

[0071] Referring to FIG. 2, a surgical instrument 112 is being used in the surgical procedure as part of the surgical system 102. The hub 106 is also configured to coordinate information flow to a display of the surgical instrument 112. For example, coordinate information flow is further described in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety. A diagnostic input or feedback entered by a non-sterile operator at the visualization tower 111 can be routed by the hub 106 to the surgical instrument display 115 within the sterile field, where it can be viewed by the operator of the surgical instrument 112. Example surgical instruments that are suitable for use with the surgical system 102 are described under the heading "Surgical

Instrument Hardware" in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety, for example.

[0072] Referring now to FIG. 3, a hub 106 is depicted in communication with a visualization system 108, a robotic system 110, and a handheld intelligent surgical instrument 112. The hub 106 includes a hub display 135, an imaging module 138, a generator module 140 (which can include a monopolar generator 142, a bipolar generator 144, and/or an ultrasonic generator 143), a communication module 130, a processor module 132, and a storage array 134. In certain aspects, as illustrated in FIG. 3, the hub 106 further includes a smoke evacuation module 126, a suction/irrigation module 128, and/or an OR mapping module 133.

[0073] During a surgical procedure, energy application to tissue, for sealing and/or cutting, is generally associated with smoke evacuation, suction of excess fluid, and/or irrigation of the tissue. Fluid, power, and/or data lines from different sources are often entangled during the surgical procedure. Valuable time can be lost addressing this issue during a surgical procedure. Detangling the lines may necessitate disconnecting the lines from their respective modules, which may require resetting the modules. The hub modular enclosure 136 offers a unified environment for managing the power, data, and fluid lines, which reduces the frequency of entanglement between such lines.

[0074] Aspects of the present disclosure present a surgical hub for use in a surgical procedure that involves energy application to tissue at a surgical site. The surgical hub includes a hub enclosure and a combo generator module slidably receivable in a docking station of the hub enclosure. The docking station includes data and power contacts. The combo generator module includes two or more of an ultrasonic energy generator component, a bipolar RF energy generator component, and a monopolar RF energy generator component that are housed in a single unit. In one aspect, the combo generator module also includes a smoke evacuation component, at least one energy delivery cable for connecting the combo generator module to a surgical instrument, at least one smoke evacuation component configured to evacuate smoke, fluid, and/or particulates generated by the application of therapeutic energy to the tissue, and a fluid line extending from the remote surgical site to the smoke evacuation component.

[0075] In one aspect, the fluid line is a first fluid line and a second fluid line extends from the remote surgical site to a suction and irrigation module slidably received in the hub enclosure. In one aspect, the hub enclosure comprises a fluid interface.

[0076] Certain surgical procedures may require the application of more than one energy type to the tissue. One energy type may be more beneficial for cutting the tissue, while another different energy type may be more beneficial for sealing the tissue. For example, a

bipolar generator can be used to seal the tissue while an ultrasonic generator can be used to cut the sealed tissue. Aspects of the present disclosure present a solution where a hub modular enclosure 136 is configured to accommodate different generators, and facilitate an interactive communication therebetween. One of the advantages of the hub modular enclosure 136 is enabling the quick removal and/or replacement of various modules.

[0077] Aspects of the present disclosure present a modular surgical enclosure for use in a surgical procedure that involves energy application to tissue. The modular surgical enclosure includes a first energy-generator module, configured to generate a first energy for application to the tissue, and a first docking station comprising a first docking port that includes first data and power contacts, wherein the first energy-generator module is slidably movable into an electrical engagement with the power and data contacts and wherein the first energy-generator module is slidably movable out of the electrical engagement with the first power and data contacts,

[0078] Further to the above, the modular surgical enclosure also includes a second energy-generator module configured to generate a second energy, different than the first energy, for application to the tissue, and a second docking station comprising a second docking port that includes second data and power contacts, wherein the second energy-generator module is slidably movable into an electrical engagement with the power and data contacts, and wherein the second energy-generator module is slidably movable out of the electrical engagement with the second power and data contacts.

[0079] In addition, the modular surgical enclosure also includes a communication bus between the first docking port and the second docking port, configured to facilitate communication between the first energy-generator module and the second energy-generator module.

[0080] Referring to FIGS. 3–7, aspects of the present disclosure are presented for a hub modular enclosure 136 that allows the modular integration of a generator module 140, a smoke evacuation module 126, and a suction/irrigation module 128. The hub modular enclosure 136 further facilitates interactive communication between the modules 140, 126, 128. As illustrated in FIG. 5, the generator module 140 can be a generator module with integrated monopolar, bipolar, and ultrasonic components supported in a single housing unit 139 slidably insertable into the hub modular enclosure 136. As illustrated in FIG. 5, the generator module 140 can be configured to connect to a monopolar device 146, a bipolar device 147, and an ultrasonic device 148. Alternatively, the generator module 140 may comprise a series of monopolar, bipolar, and/or ultrasonic generator modules that interact through the hub modular enclosure 136. The hub modular enclosure 136 can be configured to facilitate the insertion of multiple generators and interactive communication between the

generators docked into the hub modular enclosure 136 so that the generators would act as a single generator.

[0081] In one aspect, the hub modular enclosure 136 comprises a modular power and communication backplane 149 with external and wireless communication headers to enable the removable attachment of the modules 140, 126, 128 and interactive communication therebetween.

[0082] In one aspect, the hub modular enclosure 136 includes docking stations, or drawers, 151, herein also referred to as drawers, which are configured to slidably receive the modules 140, 126, 128. FIG. 4 illustrates a partial perspective view of a surgical hub enclosure 136, and a combo generator module 145 slidably receivable in a docking station 151 of the surgical hub enclosure 136. A docking port 152 with power and data contacts on a rear side of the combo generator module 145 is configured to engage a corresponding docking port 150 with power and data contacts of a corresponding docking station 151 of the hub modular enclosure 136 as the combo generator module 145 is slid into position within the corresponding docking station 151 of the hub module enclosure 136. In one aspect, the combo generator module 145 includes a bipolar, ultrasonic, and monopolar module and a smoke evacuation module integrated together into a single housing unit 139, as illustrated in FIG. 5.

[0083] In various aspects, the smoke evacuation module 126 includes a fluid line 154 that conveys captured/collected smoke and/or fluid away from a surgical site and to, for example, the smoke evacuation module 126. Vacuum suction originating from the smoke evacuation module 126 can draw the smoke into an opening of a utility conduit at the surgical site. The utility conduit, coupled to the fluid line, can be in the form of a flexible tube terminating at the smoke evacuation module 126. The utility conduit and the fluid line define a fluid path extending toward the smoke evacuation module 126 that is received in the hub enclosure 136.

[0084] In various aspects, the suction/irrigation module 128 is coupled to a surgical tool comprising an aspiration fluid line and a suction fluid line. In one example, the aspiration and suction fluid lines are in the form of flexible tubes extending from the surgical site toward the suction/irrigation module 128. One or more drive systems can be configured to cause irrigation and aspiration of fluids to and from the surgical site.

[0085] In one aspect, the surgical tool includes a shaft having an end effector at a distal end thereof and at least one energy treatment associated with the end effector, an aspiration tube, and an irrigation tube. The aspiration tube can have an inlet port at a distal end thereof and the aspiration tube extends through the shaft. Similarly, an irrigation tube can extend through the shaft and can have an inlet port in proximity to the energy deliver implement. The energy deliver implement is configured to deliver ultrasonic and/or RF energy to the

surgical site and is coupled to the generator module 140 by a cable extending initially through the shaft.

[0086] The irrigation tube can be in fluid communication with a fluid source, and the aspiration tube can be in fluid communication with a vacuum source. The fluid source and/or the vacuum source can be housed in the suction/irrigation module 128. In one example, the fluid source and/or the vacuum source can be housed in the hub enclosure 136 separately from the suction/irrigation module 128. In such example, a fluid interface can be configured to connect the suction/irrigation module 128 to the fluid source and/or the vacuum source.

[0087] In one aspect, the modules 140, 126, 128 and/or their corresponding docking stations on the hub modular enclosure 136 may include alignment features that are configured to align the docking ports of the modules into engagement with their counterparts in the docking stations of the hub modular enclosure 136. For example, as illustrated in FIG. 4, the combo generator module 145 includes side brackets 155 that are configured to slidably engage with corresponding brackets 156 of the corresponding docking station 151 of the hub modular enclosure 136. The brackets cooperate to guide the docking port contacts of the combo generator module 145 into an electrical engagement with the docking port contacts of the hub modular enclosure 136.

[0088] In some aspects, the drawers 151 of the hub modular enclosure 136 are the same, or substantially the same size, and the modules are adjusted in size to be received in the drawers 151. For example, the side brackets 155 and/or 156 can be larger or smaller depending on the size of the module. In other aspects, the drawers 151 are different in size and are each designed to accommodate a particular module.

[0089] Furthermore, the contacts of a particular module can be keyed for engagement with the contacts of a particular drawer to avoid inserting a module into a drawer with mismatching contacts.

[0090] As illustrated in FIG. 4, the docking port 150 of one drawer 151 can be coupled to the docking port 150 of another drawer 151 through a communications link 157 to facilitate an interactive communication between the modules housed in the hub modular enclosure 136. The docking ports 150 of the hub modular enclosure 136 may alternatively, or additionally, facilitate a wireless interactive communication between the modules housed in the hub modular enclosure 136. Any suitable wireless communication can be employed, such as for example Air Titan-Bluetooth.

[0091] FIG. 6 illustrates individual power bus attachments for a plurality of lateral docking ports of a lateral modular housing 160 configured to receive a plurality of modules of a surgical hub 206. The lateral modular housing 160 is configured to laterally receive and interconnect the modules 161. The modules 161 are slidably inserted into docking stations 162 of lateral modular housing 160, which includes a backplane for interconnecting the

modules 161. As illustrated in FIG. 6, the modules 161 are arranged laterally in the lateral modular housing 160. Alternatively, the modules 161 may be arranged vertically in a lateral modular housing.

[0092] FIG. 7 illustrates a vertical modular housing 164 configured to receive a plurality of modules 165 of the surgical hub 106. The modules 165 are slidably inserted into docking stations, or drawers, 167 of vertical modular housing 164, which includes a backplane for interconnecting the modules 165. Although the drawers 167 of the vertical modular housing 164 are arranged vertically, in certain instances, a vertical modular housing 164 may include drawers that are arranged laterally. Furthermore, the modules 165 may interact with one another through the docking ports of the vertical modular housing 164. In the example of FIG. 7, a display 177 is provided for displaying data relevant to the operation of the modules 165. In addition, the vertical modular housing 164 includes a master module 178 housing a plurality of sub-modules that are slidably received in the master module 178.

[0093] In various aspects, the imaging module 138 comprises an integrated video processor and a modular light source and is adapted for use with various imaging devices. In one aspect, the imaging device is comprised of a modular housing that can be assembled with a light source module and a camera module. The housing can be a disposable housing. In at least one example, the disposable housing is removably coupled to a reusable controller, a light source module, and a camera module. The light source module and/or the camera module can be selectively chosen depending on the type of surgical procedure. In one aspect, the camera module comprises a CCD sensor. In another aspect, the camera module comprises a CMOS sensor. In another aspect, the camera module is configured for scanned beam imaging. Likewise, the light source module can be configured to deliver a white light or a different light, depending on the surgical procedure.

[0094] During a surgical procedure, removing a surgical device from the surgical field and replacing it with another surgical device that includes a different camera or a different light source can be inefficient. Temporarily losing sight of the surgical field may lead to undesirable consequences. The module imaging device of the present disclosure is configured to permit the replacement of a light source module or a camera module midstream during a surgical procedure, without having to remove the imaging device from the surgical field.

[0095] In one aspect, the imaging device comprises a tubular housing that includes a plurality of channels. A first channel is configured to slidably receive the camera module, which can be configured for a snap-fit engagement with the first channel. A second channel is configured to slidably receive the light source module, which can be configured for a snap-fit engagement with the second channel. In another example, the camera module and/or the

light source module can be rotated into a final position within their respective channels. A threaded engagement can be employed in lieu of the snap-fit engagement.

[0096] In various examples, multiple imaging devices are placed at different positions in the surgical field to provide multiple views. The imaging module 138 can be configured to switch between the imaging devices to provide an optimal view. In various aspects, the imaging module 138 can be configured to integrate the images from the different imaging device.

[0097] Various image processors and imaging devices suitable for use with the present disclosure are described in U.S. Patent No. 7,995,045, titled COMBINED SBI AND CONVENTIONAL IMAGE PROCESSOR, which issued on August 9, 2011, which is herein incorporated by reference in its entirety. In addition, U.S. Patent No. 7,982,776, titled SBI MOTION ARTIFACT REMOVAL APPARATUS AND METHOD, which issued on July 19, 2011, which is herein incorporated by reference in its entirety, describes various systems for removing motion artifacts from image data. Such systems can be integrated with the imaging module 138. Furthermore, U.S. Patent Application Publication No. 2011/0306840, titled CONTROLLABLE MAGNETIC SOURCE TO FIXTURE INTRACORPOREAL APPARATUS, which published on December 15, 2011, and U.S. Patent Application Publication No. 2014/0243597, titled SYSTEM FOR PERFORMING A MINIMALLY INVASIVE SURGICAL PROCEDURE, which published on August 28, 2014, each of which is herein incorporated by reference in its entirety.

[0098] FIG. 8 illustrates a surgical data network 201 comprising a modular communication hub 203 configured to connect modular devices located in one or more operating theaters of a healthcare facility, or any room in a healthcare facility specially equipped for surgical operations, to a cloud-based system (e.g., the cloud 204 that may include a remote server 213 coupled to a storage device 205). In one aspect, the modular communication hub 203 comprises a network hub 207 and/or a network switch 209 in communication with a network router. The modular communication hub 203 also can be coupled to a local computer system 210 to provide local computer processing and data manipulation. The surgical data network 201 may be configured as passive, intelligent, or switching. A passive surgical data network serves as a conduit for the data, enabling it to go from one device (or segment) to another and to the cloud computing resources. An intelligent surgical data network includes additional features to enable the traffic passing through the surgical data network to be monitored and to configure each port in the network hub 207 or network switch 209. An intelligent surgical data network may be referred to as a manageable hub or switch. A switching hub reads the destination address of each packet and then forwards the packet to the correct port.

[0099] Modular devices 1a-1n located in the operating theater may be coupled to the modular communication hub 203. The network hub 207 and/or the network switch 209 may be coupled to a network router 211 to connect the devices 1a-1n to the cloud 204 or the local computer system 210. Data associated with the devices 1a-1n may be transferred to cloud-based computers via the router for remote data processing and manipulation. Data associated with the devices 1a-1n may also be transferred to the local computer system 210 for local data processing and manipulation. Modular devices 2a-2m located in the same operating theater also may be coupled to a network switch 209. The network switch 209 may be coupled to the network hub 207 and/or the network router 211 to connect to the devices 2a-2m to the cloud 204. Data associated with the devices 2a-2n may be transferred to the cloud 204 via the network router 211 for data processing and manipulation. Data associated with the devices 2a-2m may also be transferred to the local computer system 210 for local data processing and manipulation.

[0100] It will be appreciated that the surgical data network 201 may be expanded by interconnecting multiple network hubs 207 and/or multiple network switches 209 with multiple network routers 211. The modular communication hub 203 may be contained in a modular control tower configured to receive multiple devices 1a-1n/2a-2m. The local computer system 210 also may be contained in a modular control tower. The modular communication hub 203 is connected to a display 212 to display images obtained by some of the devices 1a-1n/2a-2m, for example during surgical procedures. In various aspects, the devices 1a-1n/2a-2m may include, for example, various modules such as an imaging module 138 coupled to an endoscope, a generator module 140 coupled to an energy-based surgical device, a smoke evacuation module 126, a suction/irrigation module 128, a communication module 130, a processor module 132, a storage array 134, a surgical device coupled to a display, and/or a non-contact sensor module, among other modular devices that may be connected to the modular communication hub 203 of the surgical data network 201.

[0101] In one aspect, the surgical data network 201 may comprise a combination of network hub(s), network switch(es), and network router(s) connecting the devices 1a-1n/2a-2m to the cloud. Any one of or all of the devices 1a-1n/2a-2m coupled to the network hub or network switch may collect data in real time and transfer the data to cloud computers for data processing and manipulation. It will be appreciated that cloud computing relies on sharing computing resources rather than having local servers or personal devices to handle software applications. The word "cloud" may be used as a metaphor for "the Internet," although the term is not limited as such. Accordingly, the term "cloud computing" may be used herein to refer to "a type of Internet-based computing," where different services—such as servers, storage, and applications—are delivered to the modular communication hub 203 and/or computer system 210 located in the surgical theater (e.g., a fixed, mobile, temporary,

or field operating room or space) and to devices connected to the modular communication hub 203 and/or computer system 210 through the Internet. The cloud infrastructure may be maintained by a cloud service provider. In this context, the cloud service provider may be the entity that coordinates the usage and control of the devices 1a-1n/2a-2m located in one or more operating theaters. The cloud computing services can perform a large number of calculations based on the data gathered by smart surgical instruments, robots, and other computerized devices located in the operating theater. The hub hardware enables multiple devices or connections to be connected to a computer that communicates with the cloud computing resources and storage.

[0102] Applying cloud computer data processing techniques on the data collected by the devices 1a-1n/2a-2m, the surgical data network provides improved surgical outcomes, reduced costs, and improved patient satisfaction. At least some of the devices 1a-1n/2a-2m may be employed to view tissue states to assess leaks or perfusion of sealed tissue after a tissue sealing and cutting procedure. At least some of the devices 1a-1n/2a-2m may be employed to identify pathology, such as the effects of diseases, using the cloud-based computing to examine data including images of samples of body tissue for diagnostic purposes. This includes localization and margin confirmation of tissue and phenotypes. At least some of the devices 1a-1n/2a-2m may be employed to identify anatomical structures of the body using a variety of sensors integrated with imaging devices and techniques such as overlaying images captured by multiple imaging devices. The data gathered by the devices 1a-1n/2a-2m, including image data, may be transferred to the cloud 204 or the local computer system 210 or both for data processing and manipulation including image processing and manipulation. The data may be analyzed to improve surgical procedure outcomes by determining if further treatment, such as the application of endoscopic intervention, emerging technologies, a targeted radiation, targeted intervention, and precise robotics to tissue-specific sites and conditions, may be pursued. Such data analysis may further employ outcome analytics processing, and using standardized approaches may provide beneficial feedback to either confirm surgical treatments and the behavior of the surgeon or suggest modifications to surgical treatments and the behavior of the surgeon.

[0103] In one implementation, the operating theater devices 1a-1n may be connected to the modular communication hub 203 over a wired channel or a wireless channel depending on the configuration of the devices 1a-1n to a network hub. The network hub 207 may be implemented, in one aspect, as a local network broadcast device that works on the physical layer of the Open System Interconnection (OSI) model. The network hub provides connectivity to the devices 1a-1n located in the same operating theater network. The network hub 207 collects data in the form of packets and sends them to the router in half duplex mode. The network hub 207 does not store any media access control/Internet

Protocol (MAC/IP) to transfer the device data. Only one of the devices 1a-1n can send data at a time through the network hub 207. The network hub 207 has no routing tables or intelligence regarding where to send information and broadcasts all network data across each connection and to a remote server 213 (FIG. 9) over the cloud 204. The network hub 207 can detect basic network errors such as collisions, but having all information broadcast to multiple ports can be a security risk and cause bottlenecks.

[0104] In another implementation, the operating theater devices 2a-2m may be connected to a network switch 209 over a wired channel or a wireless channel. The network switch 209 works in the data link layer of the OSI model. The network switch 209 is a multicast device for connecting the devices 2a-2m located in the same operating theater to the network. The network switch 209 sends data in the form of frames to the network router 211 and works in full duplex mode. Multiple devices 2a-2m can send data at the same time through the network switch 209. The network switch 209 stores and uses MAC addresses of the devices 2a-2m to transfer data.

[0105] The network hub 207 and/or the network switch 209 are coupled to the network router 211 for connection to the cloud 204. The network router 211 works in the network layer of the OSI model. The network router 211 creates a route for transmitting data packets received from the network hub 207 and/or network switch 211 to cloud-based computer resources for further processing and manipulation of the data collected by any one of or all the devices 1a-1n/2a-2m. The network router 211 may be employed to connect two or more different networks located in different locations, such as, for example, different operating theaters of the same healthcare facility or different networks located in different operating theaters of different healthcare facilities. The network router 211 sends data in the form of packets to the cloud 204 and works in full duplex mode. Multiple devices can send data at the same time. The network router 211 uses IP addresses to transfer data.

[0106] In one example, the network hub 207 may be implemented as a USB hub, which allows multiple USB devices to be connected to a host computer. The USB hub may expand a single USB port into several tiers so that there are more ports available to connect devices to the host system computer. The network hub 207 may include wired or wireless capabilities to receive information over a wired channel or a wireless channel. In one aspect, a wireless USB short-range, high-bandwidth wireless radio communication protocol may be employed for communication between the devices 1a-1n and devices 2a-2m located in the operating theater.

[0107] In other examples, the operating theater devices 1a-1n/2a-2m may communicate to the modular communication hub 203 via Bluetooth wireless technology standard for exchanging data over short distances (using short-wavelength UHF radio waves in the ISM band from 2.4 to 2.485 GHz) from fixed and mobile devices and building personal area

networks (PANs). In other aspects, the operating theater devices 1a-1n/2a-2m may communicate to the modular communication hub 203 via a number of wireless or wired communication standards or protocols, including but not limited to Wi-Fi (IEEE 802.11 family), WiMAX (IEEE 802.16 family), IEEE 802.20, long-term evolution (LTE), and Ev-DO, HSPA+, HSDPA+, HSUPA+, EDGE, GSM, GPRS, CDMA, TDMA, DECT, and Ethernet derivatives thereof, as well as any other wireless and wired protocols that are designated as 3G, 4G, 5G, and beyond. The computing module may include a plurality of communication modules. For instance, a first communication module may be dedicated to shorter-range wireless communications such as Wi-Fi and Bluetooth, and a second communication module may be dedicated to longer-range wireless communications such as GPS, EDGE, GPRS, CDMA, WiMAX, LTE, Ev-DO, and others.

[0108] The modular communication hub 203 may serve as a central connection for one or all of the operating theater devices 1a-1n/2a-2m and handles a data type known as frames. Frames carry the data generated by the devices 1a-1n/2a-2m. When a frame is received by the modular communication hub 203, it is amplified and transmitted to the network router 211, which transfers the data to the cloud computing resources by using a number of wireless or wired communication standards or protocols, as described herein.

[0109] The modular communication hub 203 can be used as a standalone device or be connected to compatible network hubs and network switches to form a larger network. The modular communication hub 203 is generally easy to install, configure, and maintain, making it a good option for networking the operating theater devices 1a-1n/2a-2m.

[0110] FIG. 9 illustrates a computer-implemented interactive surgical system 200. The computer-implemented interactive surgical system 200 is similar in many respects to the computer-implemented interactive surgical system 100. For example, the computer-implemented interactive surgical system 200 includes one or more surgical systems 202, which are similar in many respects to the surgical systems 102. Each surgical system 202 includes at least one surgical hub 206 in communication with a cloud 204 that may include a remote server 213. In one aspect, the computer-implemented interactive surgical system 200 comprises a modular control tower 236 connected to multiple operating theater devices such as, for example, intelligent surgical instruments, robots, and other computerized devices located in the operating theater. As shown in FIG. 10, the modular control tower 236 comprises a modular communication hub 203 coupled to a computer system 210. As illustrated in the example of FIG. 9, the modular control tower 236 is coupled to an imaging module 238 that is coupled to an endoscope 239, a generator module 240 that is coupled to an energy device 241, a smoke evacuator module 226, a suction/irrigation module 228, a communication module 230, a processor module 232, a storage array 234, a smart device/instrument 235 optionally coupled to a display 237, and a non-contact sensor module

242. The operating theater devices are coupled to cloud computing resources and data storage via the modular control tower 236. A robot hub 222 also may be connected to the modular control tower 236 and to the cloud computing resources. The devices/instruments 235, visualization systems 208, among others, may be coupled to the modular control tower 236 via wired or wireless communication standards or protocols, as described herein. The modular control tower 236 may be coupled to a hub display 215 (e.g., monitor, screen) to display and overlay images received from the imaging module, device/instrument display, and/or other visualization systems 208. The hub display also may display data received from devices connected to the modular control tower in conjunction with images and overlaid images.

[0111] FIG. 10 illustrates a surgical hub 206 comprising a plurality of modules coupled to the modular control tower 236. The modular control tower 236 comprises a modular communication hub 203, e.g., a network connectivity device, and a computer system 210 to provide local processing, visualization, and imaging, for example. As shown in FIG. 10, the modular communication hub 203 may be connected in a tiered configuration to expand the number of modules (e.g., devices) that may be connected to the modular communication hub 203 and transfer data associated with the modules to the computer system 210, cloud computing resources, or both. As shown in FIG. 10, each of the network hubs/switches in the modular communication hub 203 includes three downstream ports and one upstream port. The upstream network hub/switch is connected to a processor to provide a communication connection to the cloud computing resources and a local display 217. Communication to the cloud 204 may be made either through a wired or a wireless communication channel.

[0112] The surgical hub 206 employs a non-contact sensor module 242 to measure the dimensions of the operating theater and generate a map of the surgical theater using either ultrasonic or laser-type non-contact measurement devices. An ultrasound-based non-contact sensor module scans the operating theater by transmitting a burst of ultrasound and receiving the echo when it bounces off the perimeter walls of an operating theater as described under the heading "Surgical Hub Spatial Awareness Within an Operating Room" in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, which is herein incorporated by reference in its entirety, in which the sensor module is configured to determine the size of the operating theater and to adjust Bluetooth-pairing distance limits. A laser-based non-contact sensor module scans the operating theater by transmitting laser light pulses, receiving laser light pulses that bounce off the perimeter walls of the operating theater, and comparing the phase of the transmitted pulse to the received pulse to determine the size of the operating theater and to adjust Bluetooth pairing distance limits, for example.

[0113] The computer system 210 comprises a processor 244 and a network interface 245. The processor 244 is coupled to a communication module 247, storage 248, memory 249, non-volatile memory 250, and input/output interface 251 via a system bus. The system bus can be any of several types of bus structure(s) including the memory bus or memory controller, a peripheral bus or external bus, and/or a local bus using any variety of available bus architectures including, but not limited to, 9-bit bus, Industrial Standard Architecture (ISA), Micro-Charmel Architecture (MSA), Extended ISA (EISA), Intelligent Drive Electronics (IDE), VESA Local Bus (VLB), Peripheral Component Interconnect (PCI), USB, Advanced Graphics Port (AGP), Personal Computer Memory Card International Association bus (PCMCIA), Small Computer Systems Interface (SCSI), or any other proprietary bus.

[0114] The processor 244 may be any single-core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the processor may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising an on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle serial random access memory (SRAM), an internal read-only memory (ROM) loaded with StellarisWare® software, a 2 KB electrically erasable programmable read-only memory (EEPROM), and/or one or more pulse width modulation (PWM) modules, one or more quadrature encoder inputs (QEI) analogs, one or more 12-bit analog-to-digital converters (ADCs) with 12 analog input channels, details of which are available for the product datasheet.

[0115] In one aspect, the processor 244 may comprise a safety controller comprising two controller-based families such as TMS570 and RM4x, known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

[0116] The system memory includes volatile memory and non-volatile memory. The basic input/output system (BIOS), containing the basic routines to transfer information between elements within the computer system, such as during start-up, is stored in non-volatile memory. For example, the non-volatile memory can include ROM, programmable ROM (PROM), electrically programmable ROM (EPROM), EEPROM, or flash memory. Volatile memory includes random-access memory (RAM), which acts as external cache memory. Moreover, RAM is available in many forms such as SRAM, dynamic RAM (DRAM), synchronous DRAM (SDRAM), double data rate SDRAM (DDR SDRAM), enhanced SDRAM (ESDRAM), Synchlink DRAM (SLDRAM), and direct Rambus RAM (DRRAM).

[0117] The computer system 210 also includes removable/non-removable, volatile/non-volatile computer storage media, such as for example disk storage. The disk storage includes, but is not limited to, devices like a magnetic disk drive, floppy disk drive, tape drive, Jaz drive, Zip drive, LS-60 drive, flash memory card, or memory stick. In addition, the disk storage can include storage media separately or in combination with other storage media including, but not limited to, an optical disc drive such as a compact disc ROM device (CD-ROM), compact disc recordable drive (CD-R Drive), compact disc rewritable drive (CD-RW Drive), or a digital versatile disc ROM drive (DVD-ROM). To facilitate the connection of the disk storage devices to the system bus, a removable or non-removable interface may be employed.

[0118] It is to be appreciated that the computer system 210 includes software that acts as an intermediary between users and the basic computer resources described in a suitable operating environment. Such software includes an operating system. The operating system, which can be stored on the disk storage, acts to control and allocate resources of the computer system. System applications take advantage of the management of resources by the operating system through program modules and program data stored either in the system memory or on the disk storage. It is to be appreciated that various components described herein can be implemented with various operating systems or combinations of operating systems.

[0119] A user enters commands or information into the computer system 210 through input device(s) coupled to the I/O interface 251. The input devices include, but are not limited to, a pointing device such as a mouse, trackball, stylus, touch pad, keyboard, microphone, joystick, game pad, satellite dish, scanner, TV tuner card, digital camera, digital video camera, web camera, and the like. These and other input devices connect to the processor through the system bus via interface port(s). The interface port(s) include, for example, a serial port, a parallel port, a game port, and a USB. The output device(s) use some of the same types of ports as input device(s). Thus, for example, a USB port may be used to provide input to the computer system and to output information from the computer system to an output device. An output adapter is provided to illustrate that there are some output devices like monitors, displays, speakers, and printers, among other output devices that require special adapters. The output adapters include, by way of illustration and not limitation, video and sound cards that provide a means of connection between the output device and the system bus. It should be noted that other devices and/or systems of devices, such as remote computer(s), provide both input and output capabilities.

[0120] The computer system 210 can operate in a networked environment using logical connections to one or more remote computers, such as cloud computer(s), or local computers. The remote cloud computer(s) can be a personal computer, server, router,

network PC, workstation, microprocessor-based appliance, peer device, or other common network node, and the like, and typically includes many or all of the elements described relative to the computer system. For purposes of brevity, only a memory storage device is illustrated with the remote computer(s). The remote computer(s) is logically connected to the computer system through a network interface and then physically connected via a communication connection. The network interface encompasses communication networks such as local area networks (LANs) and wide area networks (WANs). LAN technologies include Fiber Distributed Data Interface (FDDI), Copper Distributed Data Interface (CDDI), Ethernet/IEEE 802.3, Token Ring/IEEE 802.5 and the like. WAN technologies include, but are not limited to, point-to-point links, circuit-switching networks like Integrated Services Digital Networks (ISDN) and variations thereon, packet-switching networks, and Digital Subscriber Lines (DSL).

[0121] In various aspects, the computer system 210 of FIG. 10, the imaging module 238 and/or visualization system 208, and/or the processor module 232 of FIGS. 9–10, may comprise an image processor, image-processing engine, media processor, or any specialized digital signal processor (DSP) used for the processing of digital images. The image processor may employ parallel computing with single instruction, multiple data (SIMD) or multiple instruction, multiple data (MIMD) technologies to increase speed and efficiency. The digital image-processing engine can perform a range of tasks. The image processor may be a system on a chip with multicore processor architecture.

[0122] The communication connection(s) refers to the hardware/software employed to connect the network interface to the bus. While the communication connection is shown for illustrative clarity inside the computer system, it can also be external to the computer system 210. The hardware/software necessary for connection to the network interface includes, for illustrative purposes only, internal and external technologies such as modems, including regular telephone-grade modems, cable modems, and DSL modems, ISDN adapters, and Ethernet cards.

[0123] In various aspects, the devices/instruments 235 described with reference to FIGS. 9-10, may be implemented as ultrasonic surgical instruments and combination energy surgical instruments 7012 as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E. Accordingly, the ultrasonic/combination surgical instrument 7012 as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E is configured to interface with the modular control tower 236 and the surgical hub 206. Once connected to the surgical hub 206, the ultrasonic/combination surgical instrument 7012 as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E is configured to interface with the cloud 204, the server 213, other hub connected instruments, the hub display 215, or

the visualization system 209, or combinations thereof. Further, once connected to hub 206, the ultrasonic/combination surgical instrument 7012 as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E may utilize the processing circuits available in the hub local computer system 210.

[0124] FIG. 11 illustrates a functional block diagram of one aspect of a USB network hub 300 device, in accordance with at least one aspect of the present disclosure. In the illustrated aspect, the USB network hub device 300 employs a TUSB2036 integrated circuit hub by Texas Instruments. The USB network hub 300 is a CMOS device that provides an upstream USB transceiver port 302 and up to three downstream USB transceiver ports 304, 306, 308 in compliance with the USB 2.0 specification. The upstream USB transceiver port 302 is a differential root data port comprising a differential data minus (DM0) input paired with a differential data plus (DP0) input. The three downstream USB transceiver ports 304, 306, 308 are differential data ports where each port includes differential data plus (DP1-DP3) outputs paired with differential data minus (DM1-DM3) outputs.

[0125] The USB network hub 300 device is implemented with a digital state machine instead of a microcontroller, and no firmware programming is required. Fully compliant USB transceivers are integrated into the circuit for the upstream USB transceiver port 302 and all downstream USB transceiver ports 304, 306, 308. The downstream USB transceiver ports 304, 306, 308 support both full-speed and low-speed devices by automatically setting the slew rate according to the speed of the device attached to the ports. The USB network hub 300 device may be configured either in bus-powered or self-powered mode and includes a hub power logic 312 to manage power.

[0126] The USB network hub 300 device includes a serial interface engine 310 (SIE). The SIE 310 is the front end of the USB network hub 300 hardware and handles most of the protocol described in chapter 8 of the USB specification. The SIE 310 typically comprehends signaling up to the transaction level. The functions that it handles could include: packet recognition, transaction sequencing, SOP, EOP, RESET, and RESUME signal detection/generation, clock/data separation, non-return-to-zero invert (NRZI) data encoding/decoding and bit-stuffing, CRC generation and checking (token and data), packet ID (PID) generation and checking/decoding, and/or serial-parallel/parallel-serial conversion. The 310 receives a clock input 314 and is coupled to a suspend/resume logic and frame timer 316 circuit and a hub repeater circuit 318 to control communication between the upstream USB transceiver port 302 and the downstream USB transceiver ports 304, 306, 308 through port logic circuits 320, 322, 324. The SIE 310 is coupled to a command decoder 326 via interface logic 328 to control commands from a serial EEPROM via a serial EEPROM interface 330.

[0127] In various aspects, the USB network hub 300 can connect 127 functions configured in up to six logical layers (tiers) to a single computer. Further, the USB network hub 300 can connect to all peripherals using a standardized four-wire cable that provides both communication and power distribution. The power configurations are bus-powered and self-powered modes. The USB network hub 300 may be configured to support four modes of power management: a bus-powered hub, with either individual-port power management or ganged-port power management, and the self-powered hub, with either individual-port power management or ganged-port power management. In one aspect, using a USB cable, the USB network hub 300, the upstream USB transceiver port 302 is plugged into a USB host controller, and the downstream USB transceiver ports 304, 306, 308 are exposed for connecting USB compatible devices, and so forth.

[0128] Additional details regarding the structure and function of the surgical hub and/or surgical hub networks can be found in U.S. Provisional Patent Application No. 62/659,900, titled METHOD OF HUB COMMUNICATION, filed April 19, 2018, which is hereby incorproated by reference herein in its entirety.

Cloud System Hardware and Functional Modules

[0129] FIG. 12 is a block diagram of the computer-implemented interactive surgical system, in accordance with at least one aspect of the present disclosure. In one aspect, the computer-implemented interactive surgical system is configured to monitor and analyze data related to the operation of various surgical systems that include surgical hubs, surgical instruments, robotic devices and operating theaters or healthcare facilities. The computer-implemented interactive surgical system comprises a cloud-based analytics system. Although the cloud-based analytics system is described as a surgical system, it is not necessarily limited as such and could be a cloud-based medical system generally. As illustrated in FIG. 12, the cloud-based analytics system comprises a plurality of surgical instruments 7012 (may be the same or similar to instruments 112), a plurality of surgical hubs 7006 (may be the same or similar to hubs 106), and a surgical data network 7001 (may be the same or similar to network 201) to couple the surgical hubs 7006 to the cloud 7004 (may be the same or similar to cloud 204). Each of the plurality of surgical hubs 7006 is communicatively coupled to one or more surgical instruments 7012. The hubs 7006 are also communicatively coupled to the cloud 7004 of the computer-implemented interactive surgical system via the network 7001. The cloud 7004 is a remote centralized source of hardware and software for storing, manipulating, and communicating data generated based on the operation of various surgical systems. As shown in FIG. 12, access to the cloud 7004 is achieved via the network 7001, which may be the Internet or some other suitable computer network. Surgical hubs 7006 that are coupled to the cloud 7004 can be considered the client

side of the cloud computing system (i.e., cloud-based analytics system). Surgical instruments 7012 are paired with the surgical hubs 7006 for control and implementation of various surgical procedures or operations as described herein.

[0130] In addition, surgical instruments 7012 may comprise transceivers for data transmission to and from their corresponding surgical hubs 7006 (which may also comprise transceivers). Combinations of surgical instruments 7012 and corresponding hubs 7006 may indicate particular locations, such as operating theaters in healthcare facilities (e.g., hospitals), for providing medical operations. For example, the memory of a surgical hub 7006 may store location data. As shown in FIG. 12, the cloud 7004 comprises central servers 7013 (which may be same or similar to remote server 113 in FIG. 1 and/or remote server 213 in FIG. 9), hub application servers 7002, data analytics modules 7034, and an input/output ("I/O") interface 7007. The central servers 7013 of the cloud 7004 collectively administer the cloud computing system, which includes monitoring requests by client surgical hubs 7006 and managing the processing capacity of the cloud 7004 for executing the requests. Each of the central servers 7013 comprises one or more processors 7008 coupled to suitable memory devices 7010 which can include volatile memory such as random-access memory (RAM) and non-volatile memory such as magnetic storage devices. The memory devices 7010 may comprise machine executable instructions that when executed cause the processors 7008 to execute the data analytics modules 7034 for the cloud-based data analysis, operations, recommendations and other operations described below. Moreover, the processors 7008 can execute the data analytics modules 7034 independently or in conjunction with hub applications independently executed by the hubs 7006. The central servers 7013 also comprise aggregated medical data databases 2212, which can reside in the memory 2210.

[0131] Based on connections to various surgical hubs 7006 via the network 7001, the cloud 7004 can aggregate data from specific data generated by various surgical instruments 7012 and their corresponding hubs 7006. Such aggregated data may be stored within the aggregated medical databases 7011 of the cloud 7004. In particular, the cloud 7004 may advantageously perform data analysis and operations on the aggregated data to yield insights and/or perform functions that individual hubs 7006 could not achieve on their own. To this end, as shown in FIG. 12, the cloud 7004 and the surgical hubs 7006 are communicatively coupled to transmit and receive information. The I/O interface 7007 is connected to the plurality of surgical hubs 7006 via the network 7001. In this way, the I/O interface 7007 can be configured to transfer information between the surgical hubs 7006 and the aggregated medical data databases 7011. Accordingly, the I/O interface 7007 may facilitate read/write operations of the cloud-based analytics system. Such read/write operations may be executed in response to requests from hubs 7006. These requests could

be transmitted to the hubs 7006 through the hub applications. The I/O interface 7007 may include one or more high speed data ports, which may include universal serial bus (USB) ports, IEEE 1394 ports, as well as Wi-Fi and Bluetooth I/O interfaces for connecting the cloud 7004 to hubs 7006. The hub application servers 7002 of the cloud 7004 are configured to host and supply shared capabilities to software applications (e.g. hub applications) executed by surgical hubs 7006. For example, the hub application servers 7002 may manage requests made by the hub applications through the hubs 7006, control access to the aggregated medical data databases 7011, and perform load balancing. The data analytics modules 7034 are described in further detail with reference to FIG. 13.

[0132] The particular cloud computing system configuration described in the present disclosure is specifically designed to address various issues arising in the context of medical operations and procedures performed using medical devices, such as the surgical instruments 7012, 112. In particular, the surgical instruments 7012 may be digital surgical devices configured to interact with the cloud 7004 for implementing techniques to improve the performance of surgical operations. Various surgical instruments 7012 and/or surgical hubs 7006 may comprise touch controlled user interfaces such that clinicians may control aspects of interaction between the surgical instruments 7012 and the cloud 7004. Other suitable user interfaces for control such as auditory controlled user interfaces can also be used.

[0133] FIG. 13 is a block diagram which illustrates the functional architecture of the computer-implemented interactive surgical system, in accordance with at least one aspect of the present disclosure. The cloud-based analytics system includes a plurality of data analytics modules 7034 that may be executed by the processors 7008 of the cloud 7004 for providing data analytic solutions to problems specifically arising in the medical field. As shown in FIG. 13, the functions of the cloud-based data analytics modules 7034 may be assisted via hub applications 7014 hosted by the hub application servers 7002 that may be accessed on surgical hubs 7006. The cloud processors 7008 and hub applications 7014 may operate in conjunction to execute the data analytics modules 7034. Application program interfaces (APIs) 7016 define the set of protocols and routines corresponding to the hub applications 7014. Additionally, the APIs 7016 manage the storing and retrieval of data into and from the aggregated medical data databases 7011 for the operations of the applications 7014. The caches 7018 also store data (e.g., temporarily) and are coupled to the APIs 7016 for more efficient retrieval of data used by the applications 7014. The data analytics modules 7034 in FIG. 13 include modules for resource optimization 7020, data collection and aggregation 7022, authorization and security 7024, control program updating 7026, patient outcome analysis 7028, recommendations 7030, and data sorting and prioritization 7032. Other suitable data analytics modules could also be implemented by the cloud 7004,

according to some aspects. In one aspect, the data analytics modules are used for specific recommendations based on analyzing trends, outcomes, and other data.

[0134] For example, the data collection and aggregation module 7022 could be used to generate self-describing data (e.g., metadata) including identification of notable features or configuration (e.g., trends), management of redundant data sets, and storage of the data in paired data sets which can be grouped by surgery but not necessarily keyed to actual surgical dates and surgeons. In particular, pair data sets generated from operations of surgical instruments 7012 can comprise applying a binary classification, e.g., a bleeding or a non-bleeding event. More generally, the binary classification may be characterized as either a desirable event (e.g., a successful surgical procedure) or an undesirable event (e.g., a misfired or misused surgical instrument 7012). The aggregated self-describing data may correspond to individual data received from various groups or subgroups of surgical hubs 7006. Accordingly, the data collection and aggregation module 7022 can generate aggregated metadata or other organized data based on raw data received from the surgical hubs 7006. To this end, the processors 7008 can be operationally coupled to the hub applications 7014 and aggregated medical data databases 7011 for executing the data analytics modules 7034. The data collection and aggregation module 7022 may store the aggregated organized data into the aggregated medical data databases 2212.

[0135] The resource optimization module 7020 can be configured to analyze this aggregated data to determine an optimal usage of resources for a particular or group of healthcare facilities. For example, the resource optimization module 7020 may determine an optimal order point of surgical stapling instruments 7012 for a group of healthcare facilities based on corresponding predicted demand of such instruments 7012. The resource optimization module 7020 might also assess the resource usage or other operational configurations of various healthcare facilities to determine whether resource usage could be improved. Similarly, the recommendations module 7030 can be configured to analyze aggregated organized data from the data collection and aggregation module 7022 to provide recommendations. For example, the recommendations module 7030 could recommend to healthcare facilities (e.g., medical service providers such as hospitals) that a particular surgical instrument 7012 should be upgraded to an improved version based on a higher than expected error rate, for example. Additionally, the recommendations module 7030 and/or resource optimization module 7020 could recommend better supply chain parameters such as product reorder points and provide suggestions of different surgical instrument 7012, uses thereof, or procedure steps to improve surgical outcomes. The healthcare facilities can receive such recommendations via corresponding surgical hubs 7006. More specific recommendations regarding parameters or configurations of various surgical instruments

7012 can also be provided. Hubs 7006 and/or surgical instruments 7012 each could also have display screens that display data or recommendations provided by the cloud 7004.

[0136] The patient outcome analysis module 7028 can analyze surgical outcomes associated with currently used operational parameters of surgical instruments 7012. The patient outcome analysis module 7028 may also analyze and assess other potential operational parameters. In this connection, the recommendations module 7030 could recommend using these other potential operational parameters based on yielding better surgical outcomes, such as better sealing or less bleeding. For example, the recommendations module 7030 could transmit recommendations to a surgical hub 7006 regarding when to use a particular cartridge for a corresponding stapling surgical instrument 7012. Thus, the cloud-based analytics system, while controlling for common variables, may be configured to analyze the large collection of raw data and to provide centralized recommendations over multiple healthcare facilities (advantageously determined based on aggregated data). For example, the cloud-based analytics system could analyze, evaluate, and/or aggregate data based on type of medical practice, type of patient, number of patients, geographic similarity between medical providers, which medical providers/facilities use similar types of instruments, etc., in a way that no single healthcare facility alone would be able to analyze independently.

[0137] The control program updating module 7026 could be configured to implement various surgical instrument 7012 recommendations when corresponding control programs are updated. For example, the patient outcome analysis module 7028 could identify correlations linking specific control parameters with successful (or unsuccessful) results. Such correlations may be addressed when updated control programs are transmitted to surgical instruments 7012 via the control program updating module 7026. Updates to instruments 7012 that are transmitted via a corresponding hub 7006 may incorporate aggregated performance data that was gathered and analyzed by the data collection and aggregation module 7022 of the cloud 7004. Additionally, the patient outcome analysis module 7028 and recommendations module 7030 could identify improved methods of using instruments 7012 based on aggregated performance data.

[0138] The cloud-based analytics system may include security features implemented by the cloud 7004. These security features may be managed by the authorization and security module 7024. Each surgical hub 7006 can have associated unique credentials such as username, password, and other suitable security credentials. These credentials could be stored in the memory 7010 and be associated with a permitted cloud access level. For example, based on providing accurate credentials, a surgical hub 7006 may be granted access to communicate with the cloud to a predetermined extent (e.g., may only engage in transmitting or receiving certain defined types of information). To this end, the aggregated

medical data databases 7011 of the cloud 7004 may comprise a database of authorized credentials for verifying the accuracy of provided credentials. Different credentials may be associated with varying levels of permission for interaction with the cloud 7004, such as a predetermined access level for receiving the data analytics generated by the cloud 7004.

[0139] Furthermore, for security purposes, the cloud could maintain a database of hubs 7006, instruments 7012, and other devices that may comprise a "black list" of prohibited devices. In particular, a surgical hub 7006 listed on the black list may not be permitted to interact with the cloud, while surgical instruments 7012 listed on the black list may not have functional access to a corresponding hub 7006 and/or may be prevented from fully functioning when paired to its corresponding hub 7006. Additionally or alternatively, the cloud 7004 may flag instruments 7012 based on incompatibility or other specified criteria. In this manner, counterfeit medical devices and improper reuse of such devices throughout the cloud-based analytics system can be identified and addressed.

[0140] The surgical instruments 7012 may use wireless transceivers to transmit wireless signals that may represent, for example, authorization credentials for access to corresponding hubs 7006 and the cloud 7004. Wired transceivers may also be used to transmit signals. Such authorization credentials can be stored in the respective memory devices of the surgical instruments 7012. The authorization and security module 7024 can determine whether the authorization credentials are accurate or counterfeit. The authorization and security module 7024 may also dynamically generate authorization credentials for enhanced security. The credentials could also be encrypted, such as by using hash based encryption. Upon transmitting proper authorization, the surgical instruments 7012 may transmit a signal to the corresponding hubs 7006 and ultimately the cloud 7004 to indicate that the instruments 7012 are ready to obtain and transmit medical data. In response, the cloud 7004 may transition into a state enabled for receiving medical data for storage into the aggregated medical data databases 7011. This data transmission readiness could be indicated by a light indicator on the instruments 7012, for example. The cloud 7004 can also transmit signals to surgical instruments 7012 for updating their associated control programs. The cloud 7004 can transmit signals that are directed to a particular class of surgical instruments 7012 (e.g., electrosurgical instruments) so that software updates to control programs are only transmitted to the appropriate surgical instruments 7012. Moreover, the cloud 7004 could be used to implement system wide solutions to address local or global problems based on selective data transmission and authorization credentials. For example, if a group of surgical instruments 7012 are identified as having a common manufacturing defect, the cloud 7004 may change the authorization credentials corresponding to this group to implement an operational lockout of the group.

[0141] The cloud-based analytics system may allow for monitoring multiple healthcare facilities (e.g., medical facilities like hospitals) to determine improved practices and recommend changes (via the recommendations module 2030, for example) accordingly. Thus, the processors 7008 of the cloud 7004 can analyze data associated with an individual healthcare facility to identify the facility and aggregate the data with other data associated with other healthcare facilities in a group. Groups could be defined based on similar operating practices or geographical location, for example. In this way, the cloud 7004 may provide healthcare facility group wide analysis and recommendations. The cloud-based analytics system could also be used for enhanced situational awareness. For example, the processors 7008 may predictively model the effects of recommendations on the cost and effectiveness for a particular facility (relative to overall operations and/or various medical procedures). The cost and effectiveness associated with that particular facility can also be compared to a corresponding local region of other facilities or any other comparable facilities.

[0142] The data sorting and prioritization module 7032 may prioritize and sort data based on criticality (e.g., the severity of a medical event associated with the data, unexpectedness, suspiciousness). This sorting and prioritization may be used in conjunction with the functions of the other data analytics modules 7034 described above to improve the cloud-based analytics and operations described herein. For example, the data sorting and prioritization module 7032 can assign a priority to the data analysis performed by the data collection and aggregation module 7022 and patient outcome analysis modules 7028. Different prioritization levels can result in particular responses from the cloud 7004 (corresponding to a level of urgency) such as escalation for an expedited response, special processing, exclusion from the aggregated medical data databases 7011, or other suitable responses. Moreover, if necessary, the cloud 7004 can transmit a request (e.g. a push message) through the hub application servers for additional data from corresponding surgical instruments 7012. The push message can result in a notification displayed on the corresponding hubs 7006 for requesting supporting or additional data. This push message may be required in situations in which the cloud detects a significant irregularity or outlier and the cloud cannot determine the cause of the irregularity. The central servers 7013 may be programmed to trigger this push message in certain significant circumstances, such as when data is determined to be different from an expected value beyond a predetermined threshold or when it appears security has been comprised, for example.

[0143] In various aspects, the surgical instrument(s) 7012 described above with reference to FIGS. 12 and 13, may be implemented as ultrasonic surgical instruments and combination energy surgical instruments 7012 as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E. Accordingly, the as ultrasonic

surgical instrument and combination energy surgical instrument 7012 as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E is configured to interface with the surgical hub 7006 and the network 2001, which is configured to interface with cloud 7004. Accordingly, the processing power provided by the central servers 7013 and the data analytics module 7034 are configured to process information (e.g., data and control) from the as ultrasonic surgical instrument and combination energy surgical instrument 7012 as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E.

[0144] Additional details regarding the cloud analysis system can be found in U.S. Provisional Patent Application No. 62/659,900, titled METHOD OF HUB COMMUNICATION, filed April 19, 2018, which is hereby incorporated by reference herein in its entirety.

Situational Awareness

[0145] Although an "intelligent" device including control algorithms that respond to sensed data can be an improvement over a "dumb" device that operates without accounting for sensed data, some sensed data can be incomplete or inconclusive when considered in isolation, i.e., without the context of the type of surgical procedure being performed or the type of tissue that is being operated on. Without knowing the procedural context (e.g., knowing the type of tissue being operated on or the type of procedure being performed), the control algorithm may control the modular device incorrectly or suboptimally given the particular context-free sensed data. For example, the optimal manner for a control algorithm to control a surgical instrument in response to a particular sensed parameter can vary according to the particular tissue type being operated on. This is due to the fact that different tissue types have different properties (e.g., resistance to tearing) and thus respond differently to actions taken by surgical instruments. Therefore, it may be desirable for a surgical instrument to take different actions even when the same measurement for a particular parameter is sensed. As one specific example, the optimal manner in which to control a surgical stapling and cutting instrument in response to the instrument sensing an unexpectedly high force to close its end effector will vary depending upon whether the tissue type is susceptible or resistant to tearing. For tissues that are susceptible to tearing, such as lung tissue, the instrument's control algorithm would optimally ramp down the motor in response to an unexpectedly high force to close to avoid tearing the tissue. For tissues that are resistant to tearing, such as stomach tissue, the instrument's control algorithm would optimally ramp up the motor in response to an unexpectedly high force to close to ensure that the end effector is clamped properly on the tissue. Without knowing whether lung or stomach tissue has been clamped, the control algorithm may make a suboptimal decision.

[0146] One solution utilizes a surgical hub including a system that is configured to derive information about the surgical procedure being performed based on data received from various data sources and then control the paired modular devices accordingly. In other words, the surgical hub is configured to infer information about the surgical procedure from received data and then control the modular devices paired to the surgical hub based upon the inferred context of the surgical procedure. FIG. 14 illustrates a diagram of a situationally aware surgical system 5100, in accordance with at least one aspect of the present disclosure. In some exemplifications, the data sources 5126 include, for example, the modular devices 5102 (which can include sensors configured to detect parameters associated with the patient and/or the modular device itself), databases 5122 (e.g., an EMR database containing patient records), and patient monitoring devices 5124 (e.g., a blood pressure (BP) monitor and an electrocardiography (EKG) monitor).

[0147] A surgical hub 5104, which may be similar to the hub 106 in many respects, can be configured to derive the contextual information pertaining to the surgical procedure from the data based upon, for example, the particular combination(s) of received data or the particular order in which the data is received from the data sources 5126. The contextual information inferred from the received data can include, for example, the type of surgical procedure being performed, the particular step of the surgical procedure that the surgeon is performing, the type of tissue being operated on, or the body cavity that is the subject of the procedure. This ability by some aspects of the surgical hub 5104 to derive or infer information related to the surgical procedure from received data can be referred to as "situational awareness." In one exemplification, the surgical hub 5104 can incorporate a situational awareness system, which is the hardware and/or programming associated with the surgical hub 5104 that derives contextual information pertaining to the surgical procedure from the received data.

[0148] The situational awareness system of the surgical hub 5104 can be configured to derive the contextual information from the data received from the data sources 5126 in a variety of different ways. In one exemplification, the situational awareness system includes a pattern recognition system, or machine learning system (e.g., an artificial neural network), that has been trained on training data to correlate various inputs (e.g., data from databases 5122, patient monitoring devices 5124, and/or modular devices 5102) to corresponding contextual information regarding a surgical procedure. In other words, a machine learning system can be trained to accurately derive contextual information regarding a surgical procedure from the provided inputs. In another exemplification, the situational awareness system can include a lookup table storing pre-characterized contextual information regarding a surgical procedure in association with one or more inputs (or ranges of inputs) corresponding to the contextual information. In response to a query with one or more inputs, the lookup table can return the corresponding contextual information for the situational

awareness system for controlling the modular devices 5102. In one exemplification, the contextual information received by the situational awareness system of the surgical hub 5104 is associated with a particular control adjustment or set of control adjustments for one or more modular devices 5102. In another exemplification, the situational awareness system includes a further machine learning system, lookup table, or other such system, which generates or retrieves one or more control adjustments for one or more modular devices 5102 when provided the contextual information as input.

[0149] A surgical hub 5104 incorporating a situational awareness system provides a number of benefits for the surgical system 5100. One benefit includes improving the interpretation of sensed and collected data, which would in turn improve the processing accuracy and/or the usage of the data during the course of a surgical procedure. To return to a previous example, a situationally aware surgical hub 5104 could determine what type of tissue was being operated on; therefore, when an unexpectedly high force to close the surgical instrument's end effector is detected, the situationally aware surgical hub 5104 could correctly ramp up or ramp down the motor of the surgical instrument for the type of tissue.

[0150] As another example, the type of tissue being operated can affect the adjustments that are made to the compression rate and load thresholds of a surgical stapling and cutting instrument for a particular tissue gap measurement. A situationally aware surgical hub 5104 could infer whether a surgical procedure being performed is a thoracic or an abdominal procedure, allowing the surgical hub 5104 to determine whether the tissue clamped by an end effector of the surgical stapling and cutting instrument is lung (for a thoracic procedure) or stomach (for an abdominal procedure) tissue. The surgical hub 5104 could then adjust the compression rate and load thresholds of the surgical stapling and cutting instrument appropriately for the type of tissue.

[0151] As yet another example, the type of body cavity being operated in during an insufflation procedure can affect the function of a smoke evacuator. A situationally aware surgical hub 5104 could determine whether the surgical site is under pressure (by determining that the surgical procedure is utilizing insufflation) and determine the procedure type. As a procedure type is generally performed in a specific body cavity, the surgical hub 5104 could then control the motor rate of the smoke evacuator appropriately for the body cavity being operated in. Thus, a situationally aware surgical hub 5104 could provide a consistent amount of smoke evacuation for both thoracic and abdominal procedures.

[0152] As yet another example, the type of procedure being performed can affect the optimal energy level for an ultrasonic surgical instrument or radio frequency (RF) electrosurgical instrument to operate at. Arthroscopic procedures, for example, require higher energy levels because the end effector of the ultrasonic surgical instrument or RF

electrosurgical instrument is immersed in fluid. A situationally aware surgical hub 5104 could determine whether the surgical procedure is an arthroscopic procedure. The surgical hub 5104 could then adjust the RF power level or the ultrasonic amplitude of the generator (i.e., "energy level") to compensate for the fluid filled environment. Relatedly, the type of tissue being operated on can affect the optimal energy level for an ultrasonic surgical instrument or RF electrosurgical instrument to operate at. A situationally aware surgical hub 5104 could determine what type of surgical procedure is being performed and then customize the energy level for the ultrasonic surgical instrument or RF electrosurgical instrument, respectively, according to the expected tissue profile for the surgical procedure. Furthermore, a situationally aware surgical hub 5104 can be configured to adjust the energy level for the ultrasonic surgical instrument or RF electrosurgical instrument throughout the course of a surgical procedure, rather than just on a procedure-by-procedure basis. A situationally aware surgical hub 5104 could determine what step of the surgical procedure is being performed or will subsequently be performed and then update the control algorithms for the generator and/or ultrasonic surgical instrument or RF electrosurgical instrument to set the energy level at a value appropriate for the expected tissue type according to the surgical procedure step.

[0153] As yet another example, data can be drawn from additional data sources 5126 to improve the conclusions that the surgical hub 5104 draws from one data source 5126. A situationally aware surgical hub 5104 could augment data that it receives from the modular devices 5102 with contextual information that it has built up regarding the surgical procedure from other data sources 5126. For example, a situationally aware surgical hub 5104 can be configured to determine whether hemostasis has occurred (i.e., whether bleeding at a surgical site has stopped) according to video or image data received from a medical imaging device. However, in some cases the video or image data can be inconclusive. Therefore, in one exemplification, the surgical hub 5104 can be further configured to compare a physiologic measurement (e.g., blood pressure sensed by a BP monitor communicably connected to the surgical hub 5104) with the visual or image data of hemostasis (e.g., from a medical imaging device 124 (FIG. 2) communicably coupled to the surgical hub 5104) to make a determination on the integrity of the staple line or tissue weld. In other words, the situational awareness system of the surgical hub 5104 can consider the physiological measurement data to provide additional context in analyzing the visualization data. The additional context can be useful when the visualization data may be inconclusive or incomplete on its own.

[0154] Another benefit includes proactively and automatically controlling the paired modular devices 5102 according to the particular step of the surgical procedure that is being performed to reduce the number of times that medical personnel are required to interact with

or control the surgical system 5100 during the course of a surgical procedure. For example, a situationally aware surgical hub 5104 could proactively activate the generator to which an RF electrosurgical instrument is connected if it determines that a subsequent step of the procedure requires the use of the instrument. Proactively activating the energy source allows the instrument to be ready for use a soon as the preceding step of the procedure is completed.

[0155] As another example, a situationally aware surgical hub 5104 could determine whether the current or subsequent step of the surgical procedure requires a different view or degree of magnification on the display according to the feature(s) at the surgical site that the surgeon is expected to need to view. The surgical hub 5104 could then proactively change the displayed view (supplied by, e.g., a medical imaging device for the visualization system 108) accordingly so that the display automatically adjusts throughout the surgical procedure.

[0156] As yet another example, a situationally aware surgical hub 5104 could determine which step of the surgical procedure is being performed or will subsequently be performed and whether particular data or comparisons between data will be required for that step of the surgical procedure. The surgical hub 5104 can be configured to automatically call up data screens based upon the step of the surgical procedure being performed, without waiting for the surgeon to ask for the particular information.

[0157] Another benefit includes checking for errors during the setup of the surgical procedure or during the course of the surgical procedure. For example, a situationally aware surgical hub 5104 could determine whether the operating theater is setup properly or optimally for the surgical procedure to be performed. The surgical hub 5104 can be configured to determine the type of surgical procedure being performed, retrieve the corresponding checklists, product location, or setup needs (e.g., from a memory), and then compare the current operating theater layout to the standard layout for the type of surgical procedure that the surgical hub 5104 determines is being performed. In one exemplification, the surgical hub 5104 can be configured to compare the list of items for the procedure scanned by a suitable scanner, for example, and/or a list of devices paired with the surgical hub 5104 to a recommended or anticipated manifest of items and/or devices for the given surgical procedure. If there are any discontinuities between the lists, the surgical hub 5104 can be configured to provide an alert indicating that a particular modular device 5102, patient monitoring device 5124, and/or other surgical item is missing. In one exemplification, the surgical hub 5104 can be configured to determine the relative distance or position of the modular devices 5102 and patient monitoring devices 5124 via proximity sensors, for example. The surgical hub 5104 can compare the relative positions of the devices to a recommended or anticipated layout for the particular surgical procedure. If there are any discontinuities between the layouts, the surgical hub 5104 can be configured to provide an

alert indicating that the current layout for the surgical procedure deviates from the recommended layout.

[0158] As another example, a situationally aware surgical hub 5104 could determine whether the surgeon (or other medical personnel) was making an error or otherwise deviating from the expected course of action during the course of a surgical procedure. For example, the surgical hub 5104 can be configured to determine the type of surgical procedure being performed, retrieve the corresponding list of steps or order of equipment usage (e.g., from a memory), and then compare the steps being performed or the equipment being used during the course of the surgical procedure to the expected steps or equipment for the type of surgical procedure that the surgical hub 5104 determined is being performed. In one exemplification, the surgical hub 5104 can be configured to provide an alert indicating that an unexpected action is being performed or an unexpected device is being utilized at the particular step in the surgical procedure.

[0159] Overall, the situational awareness system for the surgical hub 5104 improves surgical procedure outcomes by adjusting the surgical instruments (and other modular devices 5102) for the particular context of each surgical procedure (such as adjusting to different tissue types) and validating actions during a surgical procedure. The situational awareness system also improves surgeons' efficiency in performing surgical procedures by automatically suggesting next steps, providing data, and adjusting displays and other modular devices 5102 in the surgical theater according to the specific context of the procedure.

[0160] Referring now to FIG. 15, a timeline 5200 depicting situational awareness of a hub, such as the surgical hub 106 or 206 (FIGS. 1–11), for example, is depicted. The timeline 5200 is an illustrative surgical procedure and the contextual information that the surgical hub 106, 206 can derive from the data received from the data sources at each step in the surgical procedure. The timeline 5200 depicts the typical steps that would be taken by the nurses, surgeons, and other medical personnel during the course of a lung segmentectomy procedure, beginning with setting up the operating theater and ending with transferring the patient to a post-operative recovery room.

[0161] The situationally aware surgical hub 106, 206 receives data from the data sources throughout the course of the surgical procedure, including data generated each time medical personnel utilize a modular device that is paired with the surgical hub 106, 206. The surgical hub 106, 206 can receive this data from the paired modular devices and other data sources and continually derive inferences (i.e., contextual information) about the ongoing procedure as new data is received, such as which step of the procedure is being performed at any given time. The situational awareness system of the surgical hub 106, 206 is able to, for example, record data pertaining to the procedure for generating reports, verify the steps

being taken by the medical personnel, provide data or prompts (e.g., via a display screen) that may be pertinent for the particular procedural step, adjust modular devices based on the context (e.g., activate monitors, adjust the field of view (FOV) of the medical imaging device, or change the energy level of an ultrasonic surgical instrument or RF electrosurgical instrument), and take any other such action described above.

[0162] As the first step 5202 in this illustrative procedure, the hospital staff members retrieve the patient's EMR from the hospital's EMR database. Based on select patient data in the EMR, the surgical hub 106, 206 determines that the procedure to be performed is a thoracic procedure.

[0163] Second step 5204, the staff members scan the incoming medical supplies for the procedure. The surgical hub 106, 206 cross-references the scanned supplies with a list of supplies that are utilized in various types of procedures and confirms that the mix of supplies corresponds to a thoracic procedure. Further, the surgical hub 106, 206 is also able to determine that the procedure is not a wedge procedure (because the incoming supplies either lack certain supplies that are necessary for a thoracic wedge procedure or do not otherwise correspond to a thoracic wedge procedure).

[0164] Third step 5206, the medical personnel scan the patient band via a scanner that is communicably connected to the surgical hub 106, 206. The surgical hub 106, 206 can then confirm the patient's identity based on the scanned data.

[0165] Fourth step 5208, the medical staff turns on the auxiliary equipment. The auxiliary equipment being utilized can vary according to the type of surgical procedure and the techniques to be used by the surgeon, but in this illustrative case they include a smoke evacuator, insufflator, and medical imaging device. When activated, the auxiliary equipment that are modular devices can automatically pair with the surgical hub 106, 206 that is located within a particular vicinity of the modular devices as part of their initialization process. The surgical hub 106, 206 can then derive contextual information about the surgical procedure by detecting the types of modular devices that pair with it during this pre-operative or initialization phase. In this particular example, the surgical hub 106, 206 determines that the surgical procedure is a VATS procedure based on this particular combination of paired modular devices. Based on the combination of the data from the patient's EMR, the list of medical supplies to be used in the procedure, and the type of modular devices that connect to the hub, the surgical hub 106, 206 can generally infer the specific procedure that the surgical team will be performing. Once the surgical hub 106, 206 knows what specific procedure is being performed, the surgical hub 106, 206 can then retrieve the steps of that procedure from a memory or from the cloud and then cross-reference the data it subsequently receives from the connected data sources (e.g., modular devices and patient

monitoring devices) to infer what step of the surgical procedure the surgical team is performing.

[0166] Fifth step 5210, the staff members attach the EKG electrodes and other patient monitoring devices to the patient. The EKG electrodes and other patient monitoring devices are able to pair with the surgical hub 106, 206. As the surgical hub 106, 206 begins receiving data from the patient monitoring devices, the surgical hub 106, 206 thus confirms that the patient is in the operating theater.

[0167] Sixth step 5212, the medical personnel induce anesthesia in the patient. The surgical hub 106, 206 can infer that the patient is under anesthesia based on data from the modular devices and/or patient monitoring devices, including EKG data, blood pressure data, ventilator data, or combinations thereof, for example. Upon completion of the sixth step 5212, the pre-operative portion of the lung segmentectomy procedure is completed and the operative portion begins.

[0168] Seventh step 5214, the patient's lung that is being operated on is collapsed (while ventilation is switched to the contralateral lung). The surgical hub 106, 206 can infer from the ventilator data that the patient's lung has been collapsed, for example. The surgical hub 106, 206 can infer that the operative portion of the procedure has commenced as it can compare the detection of the patient's lung collapsing to the expected steps of the procedure (which can be accessed or retrieved previously) and thereby determine that collapsing the lung is the first operative step in this particular procedure.

[0169] Eighth step 5216, the medical imaging device (e.g., a scope) is inserted and video from the medical imaging device is initiated. The surgical hub 106, 206 receives the medical imaging device data (i.e., video or image data) through its connection to the medical imaging device. Upon receipt of the medical imaging device data, the surgical hub 106, 206 can determine that the laparoscopic portion of the surgical procedure has commenced. Further, the surgical hub 106, 206 can determine that the particular procedure being performed is a segmentectomy, as opposed to a lobectomy (note that a wedge procedure has already been discounted by the surgical hub 106, 206 based on data received at the second step 5204 of the procedure). The data from the medical imaging device 124 (FIG. 2) can be utilized to determine contextual information regarding the type of procedure being performed in a number of different ways, including by determining the angle at which the medical imaging device is oriented with respect to the visualization of the patient's anatomy, monitoring the number or medical imaging devices being utilized (i.e., that are activated and paired with the surgical hub 106, 206), and monitoring the types of visualization devices utilized. For example, one technique for performing a VATS lobectomy places the camera in the lower anterior corner of the patient's chest cavity above the diaphragm, whereas one technique for performing a VATS segmentectomy places the camera in an anterior intercostal position

relative to the segmental fissure. Using pattern recognition or machine learning techniques, for example, the situational awareness system can be trained to recognize the positioning of the medical imaging device according to the visualization of the patient's anatomy. As another example, one technique for performing a VATS lobectomy utilizes a single medical imaging device, whereas another technique for performing a VATS segmentectomy utilizes multiple cameras. As yet another example, one technique for performing a VATS segmentectomy utilizes an infrared light source (which can be communicably coupled to the surgical hub as part of the visualization system) to visualize the segmental fissure, which is not utilized in a VATS lobectomy. By tracking any or all of this data from the medical imaging device, the surgical hub 106, 206 can thereby determine the specific type of surgical procedure being performed and/or the technique being used for a particular type of surgical procedure.

[0170] Ninth step 5218, the surgical team begins the dissection step of the procedure. The surgical hub 106, 206 can infer that the surgeon is in the process of dissecting to mobilize the patient's lung because it receives data from the RF or ultrasonic generator indicating that an energy instrument is being fired. The surgical hub 106, 206 can cross-reference the received data with the retrieved steps of the surgical procedure to determine that an energy instrument being fired at this point in the process (i.e., after the completion of the previously discussed steps of the procedure) corresponds to the dissection step. In certain instances, the energy instrument can be an energy tool mounted to a robotic arm of a robotic surgical system.

[0171] Tenth step 5220, the surgical team proceeds to the ligation step of the procedure. The surgical hub 106, 206 can infer that the surgeon is ligating arteries and veins because it receives data from the surgical stapling and cutting instrument indicating that the instrument is being fired. Similarly to the prior step, the surgical hub 106, 206 can derive this inference by cross-referencing the receipt of data from the surgical stapling and cutting instrument with the retrieved steps in the process. In certain instances, the surgical instrument can be a surgical tool mounted to a robotic arm of a robotic surgical system.

[0172] Eleventh step 5222, the segmentectomy portion of the procedure is performed. The surgical hub 106, 206 can infer that the surgeon is transecting the parenchyma based on data from the surgical stapling and cutting instrument, including data from its cartridge. The cartridge data can correspond to the size or type of staple being fired by the instrument, for example. As different types of staples are utilized for different types of tissues, the cartridge data can thus indicate the type of tissue being stapled and/or transected. In this case, the type of staple being fired is utilized for parenchyma (or other similar tissue types), which allows the surgical hub 106, 206 to infer that the segmentectomy portion of the procedure is being performed.

[0173] Twelfth step 5224, the node dissection step is then performed. The surgical hub 106, 206 can infer that the surgical team is dissecting the node and performing a leak test based on data received from the generator indicating that an RF or ultrasonic instrument is being fired. For this particular procedure, an RF or ultrasonic instrument being utilized after parenchyma was transected corresponds to the node dissection step, which allows the surgical hub 106, 206 to make this inference. It should be noted that surgeons regularly switch back and forth between surgical stapling/cutting instruments and surgical energy (i.e., RF or ultrasonic) instruments depending upon the particular step in the procedure because different instruments are better adapted for particular tasks. Therefore, the particular sequence in which the stapling/cutting instruments and surgical energy instruments are used can indicate what step of the procedure the surgeon is performing. Moreover, in certain instances, robotic tools can be utilized for one or more steps in a surgical procedure and/or handheld surgical instruments can be utilized for one or more steps in the surgical procedure. The surgeon(s) can alternate between robotic tools and handheld surgical instruments and/or can use the devices concurrently, for example. Upon completion of the twelfth step 5224, the incisions are closed up and the post-operative portion of the procedure begins.

[0174] Thirteenth step 5226, the patient's anesthesia is reversed. The surgical hub 106, 206 can infer that the patient is emerging from the anesthesia based on the ventilator data (i.e., the patient's breathing rate begins increasing), for example.

[0175] Lastly, the fourteenth step 5228 is that the medical personnel remove the various patient monitoring devices from the patient. The surgical hub 106, 206 can thus infer that the patient is being transferred to a recovery room when the hub loses EKG, BP, and other data from the patient monitoring devices. As can be seen from the description of this illustrative procedure, the surgical hub 106, 206 can determine or infer when each step of a given surgical procedure is taking place according to data received from the various data sources that are communicably coupled to the surgical hub 106, 206.

[0176] Situational awareness is further described in U.S. Provisional Patent Application Serial No. 62/659,900, titled METHOD OF HUB COMMUNICATION, filed April 19, 2018, which is herein incorporated by reference in its entirety. In certain instances, operation of a robotic surgical system, including the various robotic surgical systems disclosed herein, for example, can be controlled by the hub 106, 206 based on its situational awareness and/or feedback from the components thereof and/or based on information from the cloud 104.

[0177] In one aspect, as described hereinbelow with reference to FIGS. 24-40, the modular device 5102 is implemented as ultrasonic surgical instruments and combination energy surgical instruments 7012 as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E. Accordingly, the modular device

5102 implemented as an ultrasonic surgical instrument and combination energy surgical instrument 7012 as described in FIGS. 23A-23B, 24A-24B,25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E is configured to operate as a data source 5126 and to interact with the database 5122 and patient monitoring devices 5124. The modular device 5102 implemented as a ultrasonic surgical instrument and combination energy surgical instrument 7012 as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E is further configured to interact with the surgical hub 5104 to provide information (e.g., data and control) to the surgical hub 5104 and receive information (e.g., data and control) from the surgical hub 5104.

[0178] In one aspect, as described hereinbelow with reference to FIGS. 24-40, the modular device 5102 is implemented as ultrasonic surgical instruments and combination energy surgical instruments 7012 as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E. Accordingly, the modular device 5102 implemented as a ultrasonic surgical instrument and combination energy surgical instrument 7012 as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E is configured to operate as a data source 5126 and to interact with the database 5122 and patient monitoring devices 5124. The modular device 5102 implemented as a ultrasonic surgical instrument and combination energy surgical instrument 7012 as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E is further configured to interact with the surgical hub 5104 to provide information (e.g., data and control) to the surgical hub 5104 and receive information (e.g., data and control) from the surgical hub 5104.

Generator Hardware

[0179] FIG. 16 is a schematic diagram of a robotic surgical instrument 700 configured to operate a surgical tool described herein according to one aspect of this disclosure. The robotic surgical instrument 700 may be programmed or configured to control distal/proximal translation of a displacement member, distal/proximal displacement of a closure tube, shaft rotation, and articulation, either with single or multiple articulation drive links. In one aspect, the surgical instrument 700 may be programmed or configured to individually control a firing member, a closure member, a shaft member, or one or more articulation members, or combinations thereof. The surgical instrument 700 comprises a control circuit 710 configured to control motor-driven firing members, closure members, shaft members, or one or more articulation members, or combinations thereof.

[0180] In one aspect, the robotic surgical instrument 700 comprises a control circuit 710 configured to control a clamp arm 716 and a closure member 714 portion of an end effector 702, an ultrasonic blade 718 coupled to an ultrasonic transducer 719 excited by an

ultrasonic generator 721, a shaft 740, and one or more articulation members 742a, 742b via a plurality of motors 704a-704e. A position sensor 734 may be configured to provide position feedback of the closure member 714 to the control circuit 710. Other sensors 738 may be configured to provide feedback to the control circuit 710. A timer/counter 731 provides timing and counting information to the control circuit 710. An energy source 712 may be provided to operate the motors 704a-704e, and a current sensor 736 provides motor current feedback to the control circuit 710. The motors 704a-704e can be operated individually by the control circuit 710 in an open-loop or closed-loop feedback control.

[0181] In one aspect, the control circuit 710 may comprise one or more microcontrollers, microprocessors, or other suitable processors for executing instructions that cause the processor or processors to perform one or more tasks. In one aspect, a timer/counter 731 provides an output signal, such as the elapsed time or a digital count, to the control circuit 710 to correlate the position of the closure member 714 as determined by the position sensor 734 with the output of the timer/counter 731 such that the control circuit 710 can determine the position of the closure member 714 at a specific time (t) relative to a starting position or the time (t) when the closure member 714 is at a specific position relative to a starting position. The timer/counter 731 may be configured to measure elapsed time, count external events, or time external events.

[0182] In one aspect, the control circuit 710 may be programmed to control functions of the end effector 702 based on one or more tissue conditions. The control circuit 710 may be programmed to sense tissue conditions, such as thickness, either directly or indirectly, as described herein. The control circuit 710 may be programmed to select a firing control program or closure control program based on tissue conditions. A firing control program may describe the distal motion of the displacement member. Different firing control programs may be selected to better treat different tissue conditions. For example, when thicker tissue is present, the control circuit 710 may be programmed to translate the displacement member at a lower velocity and/or with lower power. When thinner tissue is present, the control circuit 710 may be programmed to translate the displacement member at a higher velocity and/or with higher power. A closure control program may control the closure force applied to the tissue by the clamp arm 716. Other control programs control the rotation of the shaft 740 and the articulation members 742a, 742b.

[0183] In one aspect, the control circuit 710 may generate motor set point signals. The motor set point signals may be provided to various motor controllers 708a-708e. The motor controllers 708a-708e may comprise one or more circuits configured to provide motor drive signals to the motors 704a-704e to drive the motors 704a-704e as described herein. In some examples, the motors 704a-704e may be brushed DC electric motors. For example, the velocity of the motors 704a-704e may be proportional to the respective motor drive signals.

In some examples, the motors 704a-704e may be brushless DC electric motors, and the respective motor drive signals may comprise a PWM signal provided to one or more stator windings of the motors 704a-704e. Also, in some examples, the motor controllers 708a-708e may be omitted and the control circuit 710 may generate the motor drive signals directly.

[0184] In one aspect, the control circuit 710 may initially operate each of the motors 704a-704e in an open-loop configuration for a first open-loop portion of a stroke of the displacement member. Based on the response of the robotic surgical instrument 700 during the open-loop portion of the stroke, the control circuit 710 may select a firing control program in a closed-loop configuration. The response of the instrument may include a translation distance of the displacement member during the open-loop portion, a time elapsed during the open-loop portion, the energy provided to one of the motors 704a-704e during the open-loop portion, a sum of pulse widths of a motor drive signal, etc. After the open-loop portion, the control circuit 710 may implement the selected firing control program for a second portion of the displacement member stroke. For example, during a closed-loop portion of the stroke, the control circuit 710 may modulate one of the motors 704a-704e based on translation data describing a position of the displacement member in a closed-loop manner to translate the displacement member at a constant velocity.

[0185] In one aspect, the motors 704a-704e may receive power from an energy source 712. The energy source 712 may be a DC power supply driven by a main alternating current power source, a battery, a super capacitor, or any other suitable energy source. The motors 704a-704e may be mechanically coupled to individual movable mechanical elements such as the closure member 714, clamp arm 716, shaft 740, articulation 742a, and articulation 742b via respective transmissions 706a-706e. The transmissions 706a-706e may include one or more gears or other linkage components to couple the motors 704a-704e to movable mechanical elements. A position sensor 734 may sense a position of the closure member 714. The position sensor 734 may be or include any type of sensor that is capable of generating position data that indicate a position of the closure member 714. In some examples, the position sensor 734 may include an encoder configured to provide a series of pulses to the control circuit 710 as the closure member 714 translates distally and proximally. The control circuit 710 may track the pulses to determine the position of the closure member 714. Other suitable position sensors may be used, including, for example, a proximity sensor. Other types of position sensors may provide other signals indicating motion of the closure member 714. Also, in some examples, the position sensor 734 may be omitted. Where any of the motors 704a-704e is a stepper motor, the control circuit 710 may track the position of the closure member 714 by aggregating the number and direction of steps that the motor 704 has been instructed to execute. The position sensor 734 may be located in the end effector 702 or at any other portion of the instrument. The outputs of each

of the motors 704a-704e include a torque sensor 744a-744e to sense force and have an encoder to sense rotation of the drive shaft.

[0186] In one aspect, the control circuit 710 is configured to drive a firing member such as the closure member 714 portion of the end effector 702. The control circuit 710 provides a motor set point to a motor control 708a, which provides a drive signal to the motor 704a. The output shaft of the motor 704a is coupled to a torque sensor 744a. The torque sensor 744a is coupled to a transmission 706a which is coupled to the closure member 714. The transmission 706a comprises movable mechanical elements such as rotating elements and a firing member to control the movement of the closure member 714 distally and proximally along a longitudinal axis of the end effector 702. In one aspect, the motor 704a may be coupled to the knife gear assembly, which includes a knife gear reduction set that includes a first knife drive gear and a second knife drive gear. A torque sensor 744a provides a firing force feedback signal to the control circuit 710. The firing force signal represents the force required to fire or displace the closure member 714. A position sensor 734 may be configured to provide the position of the closure member 714 along the firing stroke or the position of the firing member as a feedback signal to the control circuit 710. The end effector 702 may include additional sensors 738 configured to provide feedback signals to the control circuit 710. When ready to use, the control circuit 710 may provide a firing signal to the motor control 708a. In response to the firing signal, the motor 704a may drive the firing member distally along the longitudinal axis of the end effector 702 from a proximal stroke start position to a stroke end position distal to the stroke start position. As the closure member 714 translates distally, the clamp arm 716 closes towards the ultrasonic blade 718.

[0187] In one aspect, the control circuit 710 is configured to drive a closure member such as the clamp arm 716 portion of the end effector 702. The control circuit 710 provides a motor set point to a motor control 708b, which provides a drive signal to the motor 704b. The output shaft of the motor 704b is coupled to a torque sensor 744b. The torque sensor 744b is coupled to a transmission 706b which is coupled to the clamp arm 716. The transmission 706b comprises movable mechanical elements such as rotating elements and a closure member to control the movement of the clamp arm 716 from the open and closed positions. In one aspect, the motor 704b is coupled to a closure gear assembly, which includes a closure reduction gear set that is supported in meshing engagement with the closure spur gear. The torque sensor 744b provides a closure force feedback signal to the control circuit 710. The closure force feedback signal represents the closure force applied to the clamp arm 716. The position sensor 734 may be configured to provide the position of the closure member as a feedback signal to the control circuit 710. Additional sensors 738 in the end effector 702 may provide the closure force feedback signal to the control circuit 710. The pivotable clamp arm 716 is positioned opposite the ultrasonic blade 718. When ready to use,

the control circuit 710 may provide a closure signal to the motor control 708b. In response to the closure signal, the motor 704b advances a closure member to grasp tissue between the clamp arm 716 and the ultrasonic blade 718.

[0188] In one aspect, the control circuit 710 is configured to rotate a shaft member such as the shaft 740 to rotate the end effector 702. The control circuit 710 provides a motor set point to a motor control 708c, which provides a drive signal to the motor 704c. The output shaft of the motor 704c is coupled to a torque sensor 744c. The torque sensor 744c is coupled to a transmission 706c which is coupled to the shaft 740. The transmission 706c comprises movable mechanical elements such as rotating elements to control the rotation of the shaft 740 clockwise or counterclockwise up to and over 360°. In one aspect, the motor 704c is coupled to the rotational transmission assembly, which includes a tube gear segment that is formed on (or attached to) the proximal end of the proximal closure tube for operable engagement by a rotational gear assembly that is operably supported on the tool mounting plate. The torque sensor 744c provides a rotation force feedback signal to the control circuit 710. The rotation force feedback signal represents the rotation force applied to the shaft 740. The position sensor 734 may be configured to provide the position of the closure member as a feedback signal to the control circuit 710. Additional sensors 738 such as a shaft encoder may provide the rotational position of the shaft 740 to the control circuit 710.

[0189] In one aspect, the control circuit 710 is configured to articulate the end effector 702. The control circuit 710 provides a motor set point to a motor control 708d, which provides a drive signal to the motor 704d. The output shaft of the motor 704d is coupled to a torque sensor 744d. The torque sensor 744d is coupled to a transmission 706d which is coupled to an articulation member 742a. The transmission 706d comprises movable mechanical elements such as articulation elements to control the articulation of the end effector 702 ±65°. In one aspect, the motor 704d is coupled to an articulation nut, which is rotatably journaled on the proximal end portion of the distal spine portion and is rotatably driven thereon by an articulation gear assembly. The torque sensor 744d provides an articulation force feedback signal to the control circuit 710. The articulation force feedback signal represents the articulation force applied to the end effector 702. Sensors 738, such as an articulation encoder, may provide the articulation position of the end effector 702 to the control circuit 710.

[0190] In another aspect, the articulation function of the robotic surgical system 700 may comprise two articulation members, or links, 742a, 742b. These articulation members 742a, 742b are driven by separate disks on the robot interface (the rack) which are driven by the two motors 708d, 708e. When the separate firing motor 704a is provided, each of articulation links 742a, 742b can be antagonistically driven with respect to the other link in order to provide a resistive holding motion and a load to the head when it is not moving and to

provide an articulation motion as the head is articulated. The articulation members 742a, 742b attach to the head at a fixed radius as the head is rotated. Accordingly, the mechanical advantage of the push-and-pull link changes as the head is rotated. This change in the mechanical advantage may be more pronounced with other articulation link drive systems.

[0191] In one aspect, the one or more motors 704a-704e may comprise a brushed DC motor with a gearbox and mechanical links to a firing member, closure member, or articulation member. Another example includes electric motors 704a-704e that operate the movable mechanical elements such as the displacement member, articulation links, closure tube, and shaft. An outside influence is an unmeasured, unpredictable influence of things like tissue, surrounding bodies, and friction on the physical system. Such outside influence can be referred to as drag, which acts in opposition to one of electric motors 704a-704e. The outside influence, such as drag, may cause the operation of the physical system to deviate from a desired operation of the physical system.

[0192] In one aspect, the position sensor 734 may be implemented as an absolute positioning system. In one aspect, the position sensor 734 may comprise a magnetic rotary absolute positioning system implemented as an AS5055EQFT single-chip magnetic rotary position sensor available from Austria Microsystems, AG. The position sensor 734 may interface with the control circuit 710 to provide an absolute positioning system. The position may include multiple Hall-effect elements located above a magnet and coupled to a CORDIC processor, also known as the digit-by-digit method and Volder's algorithm, that is provided to implement a simple and efficient algorithm to calculate hyperbolic and trigonometric functions that require only addition, subtraction, bitshift, and table lookup operations.

[0193] In one aspect, the control circuit 710 may be in communication with one or more sensors 738. The sensors 738 may be positioned on the end effector 702 and adapted to operate with the robotic surgical instrument 700 to measure the various derived parameters such as the gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors 738 may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a load cell, a pressure sensor, a force sensor, a torque sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector 702. The sensors 738 may include one or more sensors. The sensors 738 may be located on the clamp arm 716 to determine tissue location using segmented electrodes. The torque sensors 744a-744e may be configured to sense force such as firing force, closure force, and/or articulation force, among others. Accordingly, the control circuit 710 can sense (1) the closure load experienced by the distal closure tube and its position, (2) the firing member at the rack and its position, (3) what portion of the ultrasonic blade 718 has tissue on it, and (4) the load and position on both articulation rods.

[0194] In one aspect, the one or more sensors 738 may comprise a strain gauge, such as a micro-strain gauge, configured to measure the magnitude of the strain in the clamp arm 716 during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. The sensors 738 may comprise a pressure sensor configured to detect a pressure generated by the presence of compressed tissue between the clamp arm 716 and the ultrasonic blade 718. The sensors 738 may be configured to detect impedance of a tissue section located between the clamp arm 716 and the ultrasonic blade 718 that is indicative of the thickness and/or fullness of tissue located therebetween.

[0195] In one aspect, the sensors 738 may be implemented as one or more limit switches, electromechanical devices, solid-state switches, Hall-effect devices, magneto-resistive (MR) devices, giant magneto-resistive (GMR) devices, magnetometers, among others. In other implementations, the sensors 738 may be implemented as solid-state switches that operate under the influence of light, such as optical sensors, IR sensors, ultraviolet sensors, among others. Still, the switches may be solid-state devices such as transistors (e.g., FET, junction FET, MOSFET, bipolar, and the like). In other implementations, the sensors 738 may include electrical conductorless switches, ultrasonic switches, accelerometers, and inertial sensors, among others.

[0196] In one aspect, the sensors 738 may be configured to measure forces exerted on the clamp arm 716 by the closure drive system. For example, one or more sensors 738 can be at an interaction point between the closure tube and the clamp arm 716 to detect the closure forces applied by the closure tube to the clamp arm 716. The forces exerted on the clamp arm 716 can be representative of the tissue compression experienced by the tissue section captured between the clamp arm 716 and the ultrasonic blade 718. The one or more sensors 738 can be positioned at various interaction points along the closure drive system to detect the closure forces applied to the clamp arm 716 by the closure drive system. The one or more sensors 738 may be sampled in real time during a clamping operation by the processor of the control circuit 710. The control circuit 710 receives real-time sample measurements to provide and analyze time-based information and assess, in real time, closure forces applied to the clamp arm 716.

[0197] In one aspect, a current sensor 736 can be employed to measure the current drawn by each of the motors 704a-704e. The force required to advance any of the movable mechanical elements such as the closure member 714 corresponds to the current drawn by one of the motors 704a-704e. The force is converted to a digital signal and provided to the control circuit 710. The control circuit 710 can be configured to simulate the response of the actual system of the instrument in the software of the controller. A displacement member can be actuated to move the closure member 714 in the end effector 702 at or near a target

velocity. The robotic surgical instrument 700 can include a feedback controller, which can be one of any feedback controllers, including, but not limited to a PID, a state feedback, a linear-quadratic (LQR), and/or an adaptive controller, for example. The robotic surgical instrument 700 can include a power source to convert the signal from the feedback controller into a physical input such as case voltage, PWM voltage, frequency modulated voltage, current, torque, and/or force, for example. Additional details are disclosed in U.S. Patent Application Serial No. 15/636,829, titled CLOSED LOOP VELOCITY CONTROL TECHNIQUES FOR ROBOTIC SURGICAL INSTRUMENT, filed June 29, 2017, which is herein incorporated by reference in its entirety.

[0198] FIG. 17 illustrates a schematic diagram of a surgical instrument 750 configured to control the distal translation of a displacement member according to one aspect of this disclosure. In one aspect, the surgical instrument 750 is programmed to control the distal translation of a displacement member such as the closure member 764. The surgical instrument 750 comprises an end effector 752 that may comprise a clamp arm 766, a closure member 764, and an ultrasonic blade 768 coupled to an ultrasonic transducer 769 driven by an ultrasonic generator 771.

[0199] The position, movement, displacement, and/or translation of a linear displacement member, such as the closure member 764, can be measured by an absolute positioning system, sensor arrangement, and position sensor 784. Because the closure member 764 is coupled to a longitudinally movable drive member, the position of the closure member 764 can be determined by measuring the position of the longitudinally movable drive member employing the position sensor 784. Accordingly, in the following description, the position, displacement, and/or translation of the closure member 764 can be achieved by the position sensor 784 as described herein. A control circuit 760 may be programmed to control the translation of the displacement member, such as the closure member 764. The control circuit 760, in some examples, may comprise one or more microcontrollers, microprocessors, or other suitable processors for executing instructions that cause the processor or processors to control the displacement member, e.g., the closure member 764, in the manner described. In one aspect, a timer/counter 781 provides an output signal, such as the elapsed time or a digital count, to the control circuit 760 to correlate the position of the closure member 764 as determined by the position sensor 784 with the output of the timer/counter 781 such that the control circuit 760 can determine the position of the closure member 764 at a specific time (t) relative to a starting position. The timer/counter 781 may be configured to measure elapsed time, count external events, or time external events.

[0200] The control circuit 760 may generate a motor set point signal 772. The motor set point signal 772 may be provided to a motor controller 758. The motor controller 758 may comprise one or more circuits configured to provide a motor drive signal 774 to the motor

754 to drive the motor 754 as described herein. In some examples, the motor 754 may be a brushed DC electric motor. For example, the velocity of the motor 754 may be proportional to the motor drive signal 774. In some examples, the motor 754 may be a brushless DC electric motor and the motor drive signal 774 may comprise a PWM signal provided to one or more stator windings of the motor 754. Also, in some examples, the motor controller 758 may be omitted, and the control circuit 760 may generate the motor drive signal 774 directly.

[0201] The motor 754 may receive power from an energy source 762. The energy source 762 may be or include a battery, a super capacitor, or any other suitable energy source. The motor 754 may be mechanically coupled to the closure member 764 via a transmission 756. The transmission 756 may include one or more gears or other linkage components to couple the motor 754 to the closure member 764. A position sensor 784 may sense a position of the closure member 764. The position sensor 784 may be or include any type of sensor that is capable of generating position data that indicate a position of the closure member 764. In some examples, the position sensor 784 may include an encoder configured to provide a series of pulses to the control circuit 760 as the closure member 764 translates distally and proximally. The control circuit 760 may track the pulses to determine the position of the closure member 764. Other suitable position sensors may be used, including, for example, a proximity sensor. Other types of position sensors may provide other signals indicating motion of the closure member 764. Also, in some examples, the position sensor 784 may be omitted. Where the motor 754 is a stepper motor, the control circuit 760 may track the position of the closure member 764 by aggregating the number and direction of steps that the motor 754 has been instructed to execute. The position sensor 784 may be located in the end effector 752 or at any other portion of the instrument.

[0202] The control circuit 760 may be in communication with one or more sensors 788. The sensors 788 may be positioned on the end effector 752 and adapted to operate with the surgical instrument 750 to measure the various derived parameters such as gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors 788 may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a pressure sensor, a force sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector 752. The sensors 788 may include one or more sensors.

[0203] The one or more sensors 788 may comprise a strain gauge, such as a micro-strain gauge, configured to measure the magnitude of the strain in the clamp arm 766 during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. The sensors 788 may comprise a pressure sensor configured to detect a pressure generated by the presence of compressed tissue between

the clamp arm 766 and the ultrasonic blade 768. The sensors 788 may be configured to detect impedance of a tissue section located between the clamp arm 766 and the ultrasonic blade 768 that is indicative of the thickness and/or fullness of tissue located therebetween.

[0204] The sensors 788 may be is configured to measure forces exerted on the clamp arm 766 by a closure drive system. For example, one or more sensors 788 can be at an interaction point between a closure tube and the clamp arm 766 to detect the closure forces applied by a closure tube to the clamp arm 766. The forces exerted on the clamp arm 766 can be representative of the tissue compression experienced by the tissue section captured between the clamp arm 766 and the ultrasonic blade 768. The one or more sensors 788 can be positioned at various interaction points along the closure drive system to detect the closure forces applied to the clamp arm 766 by the closure drive system. The one or more sensors 788 may be sampled in real time during a clamping operation by a processor of the control circuit 760. The control circuit 760 receives real-time sample measurements to provide and analyze time-based information and assess, in real time, closure forces applied to the clamp arm 766.

[0205] A current sensor 786 can be employed to measure the current drawn by the motor 754. The force required to advance the closure member 764 corresponds to the current drawn by the motor 754. The force is converted to a digital signal and provided to the control circuit 760.

[0206] The control circuit 760 can be configured to simulate the response of the actual system of the instrument in the software of the controller. A displacement member can be actuated to move a closure member 764 in the end effector 752 at or near a target velocity. The surgical instrument 750 can include a feedback controller, which can be one of any feedback controllers, including, but not limited to a PID, a state feedback, LQR, and/or an adaptive controller, for example. The surgical instrument 750 can include a power source to convert the signal from the feedback controller into a physical input such as case voltage, PWM voltage, frequency modulated voltage, current, torque, and/or force, for example.

[0207] The actual drive system of the surgical instrument 750 is configured to drive the displacement member, cutting member, or closure member 764, by a brushed DC motor with gearbox and mechanical links to an articulation and/or knife system. Another example is the electric motor 754 that operates the displacement member and the articulation driver, for example, of an interchangeable shaft assembly. An outside influence is an unmeasured, unpredictable influence of things like tissue, surrounding bodies and friction on the physical system. Such outside influence can be referred to as drag which acts in opposition to the electric motor 754. The outside influence, such as drag, may cause the operation of the physical system to deviate from a desired operation of the physical system.

[0208] Various example aspects are directed to a surgical instrument 750 comprising an end effector 752 with motor-driven surgical sealing and cutting implements. For example, a motor 754 may drive a displacement member distally and proximally along a longitudinal axis of the end effector 752. The end effector 752 may comprise a pivotable clamp arm 766 and, when configured for use, an ultrasonic blade 768 positioned opposite the clamp arm 766. A clinician may grasp tissue between the clamp arm 766 and the ultrasonic blade 768, as described herein. When ready to use the instrument 750, the clinician may provide a firing signal, for example by depressing a trigger of the instrument 750. In response to the firing signal, the motor 754 may drive the displacement member distally along the longitudinal axis of the end effector 752 from a proximal stroke begin position to a stroke end position distal of the stroke begin position. As the displacement member translates distally, the closure member 764 with a cutting element positioned at a distal end, may cut the tissue between the ultrasonic blade 768 and the clamp arm 766.

[0209] In various examples, the surgical instrument 750 may comprise a control circuit 760 programmed to control the distal translation of the displacement member, such as the closure member 764, for example, based on one or more tissue conditions. The control circuit 760 may be programmed to sense tissue conditions, such as thickness, either directly or indirectly, as described herein. The control circuit 760 may be programmed to select a control program based on tissue conditions. A control program may describe the distal motion of the displacement member. Different control programs may be selected to better treat different tissue conditions. For example, when thicker tissue is present, the control circuit 760 may be programmed to translate the displacement member at a lower velocity and/or with lower power. When thinner tissue is present, the control circuit 760 may be programmed to translate the displacement member at a higher velocity and/or with higher power.

[0210] In some examples, the control circuit 760 may initially operate the motor 754 in an open loop configuration for a first open loop portion of a stroke of the displacement member. Based on a response of the instrument 750 during the open loop portion of the stroke, the control circuit 760 may select a firing control program. The response of the instrument may include, a translation distance of the displacement member during the open loop portion, a time elapsed during the open loop portion, energy provided to the motor 754 during the open loop portion, a sum of pulse widths of a motor drive signal, etc. After the open loop portion, the control circuit 760 may implement the selected firing control program for a second portion of the displacement member stroke. For example, during the closed loop portion of the stroke, the control circuit 760 may modulate the motor 754 based on translation data describing a position of the displacement member in a closed loop manner to translate the displacement member at a constant velocity. Additional details are disclosed in U.S. Patent

Application Serial No. 15/720,852, titled SYSTEM AND METHODS FOR CONTROLLING A DISPLAY OF A SURGICAL INSTRUMENT, filed September 29, 2017, which is herein incorporated by reference in its entirety.

[0211] FIG. 18 illustrates a schematic diagram of a surgical instrument 750 configured to control the distal translation of a displacement member according to one aspect of this disclosure. In one aspect, the surgical instrument 750 is programmed to control the distal translation of a displacement member such as the closure member 764. The surgical instrument 750 comprises an end effector 752 that may comprise a clamp arm 766, a closure member 764, and an ultrasonic blade 768 coupled to an ultrasonic transducer 769 driven by an ultrasonic generator 771.

[0212] The position, movement, displacement, and/or translation of a linear displacement member, such as the closure member 764, can be measured by an absolute positioning system, sensor arrangement, and position sensor 784. Because the closure member 764 is coupled to a longitudinally movable drive member, the position of the closure member 764 can be determined by measuring the position of the longitudinally movable drive member employing the position sensor 784. Accordingly, in the following description, the position, displacement, and/or translation of the closure member 764 can be achieved by the position sensor 784 as described herein. A control circuit 760 may be programmed to control the translation of the displacement member, such as the closure member 764. The control circuit 760, in some examples, may comprise one or more microcontrollers, microprocessors, or other suitable processors for executing instructions that cause the processor or processors to control the displacement member, e.g., the closure member 764, in the manner described. In one aspect, a timer/counter 781 provides an output signal, such as the elapsed time or a digital count, to the control circuit 760 to correlate the position of the closure member 764 as determined by the position sensor 784 with the output of the timer/counter 781 such that the control circuit 760 can determine the position of the closure member 764 at a specific time (t) relative to a starting position. The timer/counter 781 may be configured to measure elapsed time, count external events, or time external events.

[0213] The control circuit 760 may generate a motor set point signal 772. The motor set point signal 772 may be provided to a motor controller 758. The motor controller 758 may comprise one or more circuits configured to provide a motor drive signal 774 to the motor 754 to drive the motor 754 as described herein. In some examples, the motor 754 may be a brushed DC electric motor. For example, the velocity of the motor 754 may be proportional to the motor drive signal 774. In some examples, the motor 754 may be a brushless DC electric motor and the motor drive signal 774 may comprise a PWM signal provided to one or more stator windings of the motor 754. Also, in some examples, the motor controller 758 may be omitted, and the control circuit 760 may generate the motor drive signal 774 directly.

[0214] The motor 754 may receive power from an energy source 762. The energy source 762 may be or include a battery, a super capacitor, or any other suitable energy source. The motor 754 may be mechanically coupled to the closure member 764 via a transmission 756. The transmission 756 may include one or more gears or other linkage components to couple the motor 754 to the closure member 764. A position sensor 784 may sense a position of the closure member 764. The position sensor 784 may be or include any type of sensor that is capable of generating position data that indicate a position of the closure member 764. In some examples, the position sensor 784 may include an encoder configured to provide a series of pulses to the control circuit 760 as the closure member 764 translates distally and proximally. The control circuit 760 may track the pulses to determine the position of the closure member 764. Other suitable position sensors may be used, including, for example, a proximity sensor. Other types of position sensors may provide other signals indicating motion of the closure member 764. Also, in some examples, the position sensor 784 may be omitted. Where the motor 754 is a stepper motor, the control circuit 760 may track the position of the closure member 764 by aggregating the number and direction of steps that the motor 754 has been instructed to execute. The position sensor 784 may be located in the end effector 752 or at any other portion of the instrument.

[0215] The control circuit 760 may be in communication with one or more sensors 788. The sensors 788 may be positioned on the end effector 752 and adapted to operate with the surgical instrument 750 to measure the various derived parameters such as gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors 788 may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a pressure sensor, a force sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector 752. The sensors 788 may include one or more sensors.

[0216] The one or more sensors 788 may comprise a strain gauge, such as a micro-strain gauge, configured to measure the magnitude of the strain in the clamp arm 766 during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. The sensors 788 may comprise a pressure sensor configured to detect a pressure generated by the presence of compressed tissue between the clamp arm 766 and the ultrasonic blade 768. The sensors 788 may be configured to detect impedance of a tissue section located between the clamp arm 766 and the ultrasonic blade 768 that is indicative of the thickness and/or fullness of tissue located therebetween.

[0217] The sensors 788 may be is configured to measure forces exerted on the clamp arm 766 by a closure drive system. For example, one or more sensors 788 can be at an interaction point between a closure tube and the clamp arm 766 to detect the closure forces

applied by a closure tube to the clamp arm 766. The forces exerted on the clamp arm 766 can be representative of the tissue compression experienced by the tissue section captured between the clamp arm 766 and the ultrasonic blade 768. The one or more sensors 788 can be positioned at various interaction points along the closure drive system to detect the closure forces applied to the clamp arm 766 by the closure drive system. The one or more sensors 788 may be sampled in real time during a clamping operation by a processor of the control circuit 760. The control circuit 760 receives real-time sample measurements to provide and analyze time-based information and assess, in real time, closure forces applied to the clamp arm 766.

[0218] A current sensor 786 can be employed to measure the current drawn by the motor 754. The force required to advance the closure member 764 corresponds to the current drawn by the motor 754. The force is converted to a digital signal and provided to the control circuit 760.

[0219] The control circuit 760 can be configured to simulate the response of the actual system of the instrument in the software of the controller. A displacement member can be actuated to move a closure member 764 in the end effector 752 at or near a target velocity. The surgical instrument 750 can include a feedback controller, which can be one of any feedback controllers, including, but not limited to a PID, a state feedback, LQR, and/or an adaptive controller, for example. The surgical instrument 750 can include a power source to convert the signal from the feedback controller into a physical input such as case voltage, PWM voltage, frequency modulated voltage, current, torque, and/or force, for example.

[0220] The actual drive system of the surgical instrument 750 is configured to drive the displacement member, cutting member, or closure member 764, by a brushed DC motor with gearbox and mechanical links to an articulation and/or knife system. Another example is the electric motor 754 that operates the displacement member and the articulation driver, for example, of an interchangeable shaft assembly. An outside influence is an unmeasured, unpredictable influence of things like tissue, surrounding bodies and friction on the physical system. Such outside influence can be referred to as drag which acts in opposition to the electric motor 754. The outside influence, such as drag, may cause the operation of the physical system to deviate from a desired operation of the physical system.

[0221] Various example aspects are directed to a surgical instrument 750 comprising an end effector 752 with motor-driven surgical sealing and cutting implements. For example, a motor 754 may drive a displacement member distally and proximally along a longitudinal axis of the end effector 752. The end effector 752 may comprise a pivotable clamp arm 766 and, when configured for use, an ultrasonic blade 768 positioned opposite the clamp arm 766. A clinician may grasp tissue between the clamp arm 766 and the ultrasonic blade 768, as described herein. When ready to use the instrument 750, the clinician may provide a firing

signal, for example by depressing a trigger of the instrument 750. In response to the firing signal, the motor 754 may drive the displacement member distally along the longitudinal axis of the end effector 752 from a proximal stroke begin position to a stroke end position distal of the stroke begin position. As the displacement member translates distally, the closure member 764 with a cutting element positioned at a distal end, may cut the tissue between the ultrasonic blade 768 and the clamp arm 766.

[0222] In various examples, the surgical instrument 750 may comprise a control circuit 760 programmed to control the distal translation of the displacement member, such as the closure member 764, for example, based on one or more tissue conditions. The control circuit 760 may be programmed to sense tissue conditions, such as thickness, either directly or indirectly, as described herein. The control circuit 760 may be programmed to select a control program based on tissue conditions. A control program may describe the distal motion of the displacement member. Different control programs may be selected to better treat different tissue conditions. For example, when thicker tissue is present, the control circuit 760 may be programmed to translate the displacement member at a lower velocity and/or with lower power. When thinner tissue is present, the control circuit 760 may be programmed to translate the displacement member at a higher velocity and/or with higher power.

[0223] In some examples, the control circuit 760 may initially operate the motor 754 in an open loop configuration for a first open loop portion of a stroke of the displacement member. Based on a response of the instrument 750 during the open loop portion of the stroke, the control circuit 760 may select a firing control program. The response of the instrument may include, a translation distance of the displacement member during the open loop portion, a time elapsed during the open loop portion, energy provided to the motor 754 during the open loop portion, a sum of pulse widths of a motor drive signal, etc. After the open loop portion, the control circuit 760 may implement the selected firing control program for a second portion of the displacement member stroke. For example, during the closed loop portion of the stroke, the control circuit 760 may modulate the motor 754 based on translation data describing a position of the displacement member in a closed loop manner to translate the displacement member at a constant velocity. Additional details are disclosed in U.S. Patent Application Serial No. 15/720,852, titled SYSTEM AND METHODS FOR CONTROLLING A DISPLAY OF A SURGICAL INSTRUMENT, filed September 29, 2017, which is herein incorporated by reference in its entirety.

[0224] FIG. 18 is a schematic diagram of a surgical instrument 790 configured to control various functions according to one aspect of this disclosure. In one aspect, the surgical instrument 790 is programmed to control distal translation of a displacement member such as the closure member 764. The surgical instrument 790 comprises an end effector 792 that

may comprise a clamp arm 766, a closure member 764, and an ultrasonic blade 768 which may be interchanged with or work in conjunction with one or more RF electrodes 796 (shown in dashed line). The ultrasonic blade 768 is coupled to an ultrasonic transducer 769 driven by an ultrasonic generator 771.

[0225] In one aspect, sensors 788 may be implemented as a limit switch, electromechanical device, solid-state switches, Hall-effect devices, MR devices, GMR devices, magnetometers, among others. In other implementations, the sensors 638 may be solid-state switches that operate under the influence of light, such as optical sensors, IR sensors, ultraviolet sensors, among others. Still, the switches may be solid-state devices such as transistors (e.g., FET, junction FET, MOSFET, bipolar, and the like). In other implementations, the sensors 788 may include electrical conductorless switches, ultrasonic switches, accelerometers, and inertial sensors, among others.

[0226] In one aspect, the position sensor 784 may be implemented as an absolute positioning system comprising a magnetic rotary absolute positioning system implemented as an AS5055EQFT single-chip magnetic rotary position sensor available from Austria Microsystems, AG. The position sensor 784 may interface with the control circuit 760 to provide an absolute positioning system. The position may include multiple Hall-effect elements located above a magnet and coupled to a CORDIC processor, also known as the digit-by-digit method and Volder's algorithm, that is provided to implement a simple and efficient algorithm to calculate hyperbolic and trigonometric functions that require only addition, subtraction, bitshift, and table lookup operations.

[0227] In some examples, the position sensor 784 may be omitted. Where the motor 754 is a stepper motor, the control circuit 760 may track the position of the closure member 764 by aggregating the number and direction of steps that the motor has been instructed to execute. The position sensor 784 may be located in the end effector 792 or at any other portion of the instrument.

[0228] The control circuit 760 may be in communication with one or more sensors 788. The sensors 788 may be positioned on the end effector 792 and adapted to operate with the surgical instrument 790 to measure the various derived parameters such as gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors 788 may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a pressure sensor, a force sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector 792. The sensors 788 may include one or more sensors.

[0229] An RF energy source 794 is coupled to the end effector 792 and is applied to the RF electrode 796 when the RF electrode 796 is provided in the end effector 792 in place of

the ultrasonic blade 768 or to work in conjunction with the ultrasonic blade 768. For example, the ultrasonic blade is made of electrically conductive metal and may be employed as the return path for electrosurgical RF current. The control circuit 760 controls the delivery of the RF energy to the RF electrode 796.

[0230] Additional details are disclosed in U.S. Patent Application Serial No. 15/636,096, titled SURGICAL SYSTEM COUPLABLE WITH STAPLE CARTRIDGE AND RADIO FREQUENCY CARTRIDGE, AND METHOD OF USING SAME, filed June 28, 2017, which is herein incorporated by reference in its entirety.

[0231] FIG. 19 illustrates an example of a generator 900, which is one form of a generator configured to couple to an ultrasonic instrument and further configured to execute adaptive ultrasonic blade control algorithms in a surgical data network comprising a modular communication hub. The generator 900 is configured to deliver multiple energy modalities to a surgical instrument. The generator 900 provides RF and ultrasonic signals for delivering energy to a surgical instrument either independently or simultaneously. The RF and ultrasonic signals may be provided alone or in combination and may be provided simultaneously. As noted above, at least one generator output can deliver multiple energy modalities (e.g., ultrasonic, bipolar or monopolar RF, irreversible and/or reversible electroporation, and/or microwave energy, among others) through a single port, and these signals can be delivered separately or simultaneously to the end effector to treat tissue. The generator 900 comprises a processor 902 coupled to a waveform generator 904. The processor 902 and waveform generator 904 are configured to generate a variety of signal waveforms based on information stored in a memory coupled to the processor 902, not shown for clarity of disclosure. The digital information associated with a waveform is provided to the waveform generator 904 which includes one or more DAC circuits to convert the digital input into an analog output. The analog output is fed to an amplifier 1106 for signal conditioning and amplification. The conditioned and amplified output of the amplifier 906 is coupled to a power transformer 908. The signals are coupled across the power transformer 908 to the secondary side, which is in the patient isolation side. A first signal of a first energy modality is provided to the surgical instrument between the terminals labeled $ENERGY_1$ and RETURN. A second signal of a second energy modality is coupled across a capacitor 910 and is provided to the surgical instrument between the terminals labeled $ENERGY_2$ and RETURN. It will be appreciated that more than two energy modalities may be output and thus the subscript "n" may be used to designate that up to n $ENERGY_n$ terminals may be provided, where n is a positive integer greater than 1. It also will be appreciated that up to "n" return paths $RETURN_n$ may be provided without departing from the scope of the present disclosure.

[0232] A first voltage sensing circuit 912 is coupled across the terminals labeled $ENERGY_1$ and the RETURN path to measure the output voltage therebetween. A second voltage sensing circuit 924 is coupled across the terminals labeled $ENERGY_2$ and the RETURN path to measure the output voltage therebetween. A current sensing circuit 914 is disposed in series with the RETURN leg of the secondary side of the power transformer 908 as shown to measure the output current for either energy modality. If different return paths are provided for each energy modality, then a separate current sensing circuit should be provided in each return leg. The outputs of the first and second voltage sensing circuits 912, 924 are provided to respective isolation transformers 916, 922 and the output of the current sensing circuit 914 is provided to another isolation transformer 918. The outputs of the isolation transformers 916, 928, 922 in the on the primary side of the power transformer 908 (non-patient isolated side) are provided to a one or more ADC circuit 926. The digitized output of the ADC circuit 926 is provided to the processor 902 for further processing and computation. The output voltages and output current feedback information can be employed to adjust the output voltage and current provided to the surgical instrument and to compute output impedance, among other parameters. Input/output communications between the processor 902 and patient isolated circuits is provided through an interface circuit 920. Sensors also may be in electrical communication with the processor 902 by way of the interface circuit 920.

[0233] In one aspect, the impedance may be determined by the processor 902 by dividing the output of either the first voltage sensing circuit 912 coupled across the terminals labeled $ENERGY_1$/RETURN or the second voltage sensing circuit 924 coupled across the terminals labeled $ENERGY_2$/RETURN by the output of the current sensing circuit 914 disposed in series with the RETURN leg of the secondary side of the power transformer 908. The outputs of the first and second voltage sensing circuits 912, 924 are provided to separate isolations transformers 916, 922 and the output of the current sensing circuit 914 is provided to another isolation transformer 916. The digitized voltage and current sensing measurements from the ADC circuit 926 are provided the processor 902 for computing impedance. As an example, the first energy modality $ENERGY_1$ may be ultrasonic energy and the second energy modality $ENERGY_2$ may be RF energy. Nevertheless, in addition to ultrasonic and bipolar or monopolar RF energy modalities, other energy modalities include irreversible and/or reversible electroporation and/or microwave energy, among others. Also, although the example illustrated in FIG. 19 shows a single return path RETURN may be provided for two or more energy modalities, in other aspects, multiple return paths $RETURN_n$ may be provided for each energy modality $ENERGY_n$. Thus, as described herein, the ultrasonic transducer impedance may be measured by dividing the output of the first voltage sensing circuit 912 by the current sensing circuit 914 and the tissue impedance may be

measured by dividing the output of the second voltage sensing circuit 924 by the current sensing circuit 914.

[0234] As shown in FIG. 19, the generator 900 comprising at least one output port can include a power transformer 908 with a single output and with multiple taps to provide power in the form of one or more energy modalities, such as ultrasonic, bipolar or monopolar RF, irreversible and/or reversible electroporation, and/or microwave energy, among others, for example, to the end effector depending on the type of treatment of tissue being performed. For example, the generator 900 can deliver energy with higher voltage and lower current to drive an ultrasonic transducer, with lower voltage and higher current to drive RF electrodes for sealing tissue, or with a coagulation waveform for spot coagulation using either monopolar or bipolar RF electrosurgical electrodes. The output waveform from the generator 900 can be steered, switched, or filtered to provide the frequency to the end effector of the surgical instrument. The connection of an ultrasonic transducer to the generator 900 output would be preferably located between the output labeled $ENERGY_1$ and RETURN as shown in FIG. 18. In one example, a connection of RF bipolar electrodes to the generator 900 output would be preferably located between the output labeled $ENERGY_2$ and RETURN. In the case of monopolar output, the preferred connections would be active electrode (e.g., pencil or other probe) to the $ENERGY_2$ output and a suitable return pad connected to the RETURN output.

[0235] Additional details are disclosed in U.S. Patent Application Publication No. 2017/0086914, titled TECHNIQUES FOR OPERATING GENERATOR FOR DIGITALLY GENERATING ELECTRICAL SIGNAL WAVEFORMS AND SURGICAL INSTRUMENTS, which published on March 30, 2017, which is herein incorporated by reference in its entirety.

[0236] As used throughout this description, the term "wireless" and its derivatives may be used to describe circuits, devices, systems, methods, techniques, communications channels, etc., that may communicate data through the use of modulated electromagnetic radiation through a non-solid medium. The term does not imply that the associated devices do not contain any wires, although in some aspects they might not. The communication module may implement any of a number of wireless or wired communication standards or protocols, including but not limited to Wi-Fi (IEEE 802.11 family), WiMAX (IEEE 802.16 family), IEEE 802.20, long term evolution (LTE), Ev-DO, HSPA+, HSDPA+, HSUPA+, EDGE, GSM, GPRS, CDMA, TDMA, DECT, Bluetooth, Ethernet derivatives thereof, as well as any other wireless and wired protocols that are designated as 3G, 4G, 5G, and beyond. The computing module may include a plurality of communication modules. For instance, a first communication module may be dedicated to shorter range wireless communications such as Wi-Fi and Bluetooth and a second communication module may be dedicated to longer range

wireless communications such as GPS, EDGE, GPRS, CDMA, WiMAX, LTE, Ev-DO, and others.

[0237] As used herein a processor or processing unit is an electronic circuit which performs operations on some external data source, usually memory or some other data stream. The term is used herein to refer to the central processor (central processing unit) in a system or computer systems (especially systems on a chip (SoCs)) that combine a number of specialized "processors."

[0238] As used herein, a system on a chip or system on chip (SoC or SOC) is an integrated circuit (also known as an "IC" or "chip") that integrates all components of a computer or other electronic systems. It may contain digital, analog, mixed-signal, and often radio-frequency functions—all on a single substrate. A SoC integrates a microcontroller (or microprocessor) with advanced peripherals like graphics processing unit (GPU), Wi-Fi module, or coprocessor. A SoC may or may not contain built-in memory.

[0239] As used herein, a microcontroller or controller is a system that integrates a microprocessor with peripheral circuits and memory. A microcontroller (or MCU for microcontroller unit) may be implemented as a small computer on a single integrated circuit. It may be similar to a SoC; an SoC may include a microcontroller as one of its components. A microcontroller may contain one or more core processing units (CPUs) along with memory and programmable input/output peripherals. Program memory in the form of Ferroelectric RAM, NOR flash or OTP ROM is also often included on chip, as well as a small amount of RAM. Microcontrollers may be employed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications consisting of various discrete chips.

[0240] As used herein, the term controller or microcontroller may be a stand-alone IC or chip device that interfaces with a peripheral device. This may be a link between two parts of a computer or a controller on an external device that manages the operation of (and connection with) that device.

[0241] Any of the processors or microcontrollers described herein, may be implemented by any single core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the processor may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle serial random access memory (SRAM), internal read-only memory (ROM) loaded with StellarisWare® software, 2 KB electrically erasable programmable read-only memory (EEPROM), one or more pulse width modulation (PWM) modules, one or more quadrature

encoder inputs (QEI) analog, one or more 12-bit Analog-to-Digital Converters (ADC) with 12 analog input channels, details of which are available for the product datasheet.

[0242] In one aspect, the processor may comprise a safety controller comprising two controller-based families such as TMS570 and RM4x known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

[0243] Modular devices include the modules (as described in connection with FIGS. 3 and 9, for example) that are receivable within a surgical hub and the surgical devices or instruments that can be connected to the various modules in order to connect or pair with the corresponding surgical hub. The modular devices include, for example, intelligent surgical instruments, medical imaging devices, suction/irrigation devices, smoke evacuators, energy generators, ventilators, insufflators, and displays. The modular devices described herein can be controlled by control algorithms. The control algorithms can be executed on the modular device itself, on the surgical hub to which the particular modular device is paired, or on both the modular device and the surgical hub (e.g., via a distributed computing architecture). In some exemplifications, the modular devices' control algorithms control the devices based on data sensed by the modular device itself (i.e., by sensors in, on, or connected to the modular device). This data can be related to the patient being operated on (e.g., tissue properties or insufflation pressure) or the modular device itself (e.g., the rate at which a knife is being advanced, motor current, or energy levels). For example, a control algorithm for a surgical stapling and cutting instrument can control the rate at which the instrument's motor drives its knife through tissue according to resistance encountered by the knife as it advances.

[0244] FIG. 20 is a simplified block diagram of one aspect of the generator 1100 for providing inductorless tuning as described above, among other benefits. With reference to FIG. 20, the generator 1100 may comprise a patient isolated stage 1520 in communication with a non-isolated stage 1540 via a power transformer 1560. A secondary winding 1580 of the power transformer 1560 is contained in the isolated stage 1520 and may comprise a tapped configuration (e.g., a center-tapped or non-center tapped configuration) to define drive signal outputs 1600a, 1600b, 1600c for outputting drive signals to different surgical devices, such as, for example, an ultrasonic surgical device 1104 and an electrosurgical device 1106. In particular, drive signal outputs 1600a, 1600b, 1600c may output a drive signal (e.g., a 420V RMS drive signal) to an ultrasonic surgical device 1104, and drive signal outputs 1600a, 1600b, 1600c may output a drive signal (e.g., a 100V RMS drive signal) to an electrosurgical device 1106, with output 1600b corresponding to the center tap of the power transformer 1560. The non-isolated stage 1540 may comprise a power amplifier 1620 having

an output connected to a primary winding 1640 of the power transformer 1560. In certain aspects the power amplifier 1620 may comprise a push-pull amplifier, for example. The non-isolated stage 1540 may further comprise a programmable logic device 1660 for supplying a digital output to a digital-to-analog converter (DAC) 1680, which in turn supplies a corresponding analog signal to an input of the power amplifier 1620. In certain aspects the programmable logic device 1660 may comprise a field-programmable gate array (FPGA), for example. The programmable logic device 1660, by virtue of controlling the power amplifier's 1620 input via the DAC 1680, may therefore control any of a number of parameters (e.g., frequency, waveform shape, waveform amplitude) of drive signals appearing at the drive signal outputs 1600a, 1600b, 1600c. In certain aspects and as discussed below, the programmable logic device 1660, in conjunction with a processor (e.g., processor 1740 discussed below), may implement a number of digital signal processing (DSP)-based and/or other control algorithms to control parameters of the drive signals output by the generator 1100.

[0245] Power may be supplied to a power rail of the power amplifier 1620 by a switch-mode regulator 1700. In certain aspects the switch-mode regulator 1700 may comprise an adjustable buck regulator, for example. As discussed above, the non-isolated stage 1540 may further comprise a processor 1740, which in one aspect may comprise a DSP processor such as an ADSP-21469 SHARC DSP, available from Analog Devices, Norwood, Mass., for example. In certain aspects the processor 1740 may control operation of the switch-mode power converter 1700 responsive to voltage feedback data received from the power amplifier 1620 by the processor 1740 via an analog-to-digital converter (ADC) 1760. In one aspect, for example, the processor 1740 may receive as input, via the ADC 1760, the waveform envelope of a signal (e.g., an RF signal) being amplified by the power amplifier 1620. The processor 1740 may then control the switch-mode regulator 1700 (e.g., via a pulse-width modulated (PWM) output) such that the rail voltage supplied to the power amplifier 1620 tracks the waveform envelope of the amplified signal. By dynamically modulating the rail voltage of the power amplifier 1620 based on the waveform envelope, the efficiency of the power amplifier 1620 may be significantly improved relative to a fixed rail voltage amplifier scheme. The processor 1740 may be configured for wired or wireless communication.

[0246] In certain aspects, the programmable logic device 1660, in conjunction with the processor 1740, may implement a direct digital synthesizer (DDS) control scheme to control the waveform shape, frequency and/or amplitude of drive signals output by the generator 1100. In one aspect, for example, the programmable logic device 1660 may implement a DDS control algorithm by recalling waveform samples stored in a dynamically-updated look-up table (LUT), such as a RAM LUT which may be embedded in an FPGA. This control

algorithm is particularly useful for ultrasonic applications in which an ultrasonic transducer, such as the ultrasonic transducer 1120, may be driven by a clean sinusoidal current at its resonant frequency. Because other frequencies may excite parasitic resonances, minimizing or reducing the total distortion of the motional branch current may correspondingly minimize or reduce undesirable resonance effects. Because the waveform shape of a drive signal output by the generator 1100 is impacted by various sources of distortion present in the output drive circuit (e.g., the power transformer 1560, the power amplifier 1620), voltage and current feedback data based on the drive signal may be input into an algorithm, such as an error control algorithm implemented by the processor 1740, which compensates for distortion by suitably pre-distorting or modifying the waveform samples stored in the LUT on a dynamic, ongoing basis (e.g., in real-time). In one aspect, the amount or degree of pre-distortion applied to the LUT samples may be based on the error between a computed motional branch current and a desired current waveform shape, with the error being determined on a sample-by sample basis. In this way, the pre-distorted LUT samples, when processed through the drive circuit, may result in a motional branch drive signal having the desired waveform shape (e.g., sinusoidal) for optimally driving the ultrasonic transducer. In such aspects, the LUT waveform samples will therefore not represent the desired waveform shape of the drive signal, but rather the waveform shape that is required to ultimately produce the desired waveform shape of the motional branch drive signal when distortion effects are taken into account.

[0247] The non-isolated stage 1540 may further comprise an ADC 1780 and an ADC 1800 coupled to the output of the power transformer 1560 via respective isolation transformers 1820, 1840 for respectively sampling the voltage and current of drive signals output by the generator 1100. In certain aspects, the ADCs 1780, 1800 may be configured to sample at high speeds (e.g., 80 Msps) to enable oversampling of the drive signals. In one aspect, for example, the sampling speed of the ADCs 1780, 1800 may enable approximately 200X (depending on drive frequency) oversampling of the drive signals. In certain aspects, the sampling operations of the ADCs 1780, 1800 may be performed by a single ADC receiving input voltage and current signals via a two-way multiplexer. The use of high-speed sampling in aspects of the generator 1100 may enable, among other things, calculation of the complex current flowing through the motional branch (which may be used in certain aspects to implement DDS-based waveform shape control described above), accurate digital filtering of the sampled signals, and calculation of real power consumption with a high degree of precision. Voltage and current feedback data output by the ADCs 1780, 1800 may be received and processed (e.g., FIFO buffering, multiplexing) by the programmable logic device 1660 and stored in data memory for subsequent retrieval by, for example, the processor 1740. As noted above, voltage and current feedback data may be used as input to

an algorithm for pre-distorting or modifying LUT waveform samples on a dynamic and ongoing basis. In certain aspects, this may require each stored voltage and current feedback data pair to be indexed based on, or otherwise associated with, a corresponding LUT sample that was output by the programmable logic device 1660 when the voltage and current feedback data pair was acquired. Synchronization of the LUT samples and the voltage and current feedback data in this manner contributes to the correct timing and stability of the pre-distortion algorithm.

[0248] In certain aspects, the voltage and current feedback data may be used to control the frequency and/or amplitude (e.g., current amplitude) of the drive signals. In one aspect, for example, voltage and current feedback data may be used to determine impedance phase, e.g., the phase difference between the voltage and current drive signals. The frequency of the drive signal may then be controlled to minimize or reduce the difference between the determined impedance phase and an impedance phase setpoint (e.g., 0°), thereby minimizing or reducing the effects of harmonic distortion and correspondingly enhancing impedance phase measurement accuracy. The determination of phase impedance and a frequency control signal may be implemented in the processor 1740, for example, with the frequency control signal being supplied as input to a DDS control algorithm implemented by the programmable logic device 1660.

[0249] The impedance phase may be determined through Fourier analysis. In one aspect, the phase difference between the generator voltage $V_g(t)$ and generator current $I_g(t)$ driving signals may be determined using the Fast Fourier Transform (FFT) or the Discrete Fourier Transform (DFT) as follows:

[0250] $V_g(t) = A_1\cos(2\pi f_0 t + \varphi_1)$

[0251] $I_g(t) = A_2\cos(2\pi f_0 t + \varphi_2)$

[0252] $V_g(f) = \frac{A_1}{2}\big(\delta(f - f_0) + \delta(f + f_0)\big)exp(j2\pi f\frac{\varphi_1}{2\pi f_0})$

[0253] $I_g(f) = \frac{A_2}{2}\big(\delta(f - f_0) + \delta(f + f_0)\big)\exp(j2\pi f\frac{\varphi_2}{2\pi f_0})$

[0254] Evaluating the Fourier Transform at the frequency of the sinusoid yields:

[0255] $V_g(f_0) = \frac{A_1}{2}\delta(0)\exp(j\varphi_1) \qquad \arg V(f_0) = \varphi_1$

[0256] $I_g(f_0) = \frac{A_2}{2}\delta(0)\exp(j\varphi_2) \qquad \arg I(f_0) = \varphi_2$

[0257] Other approaches include weighted least-squares estimation, Kalman filtering, and space-vector-based techniques. Virtually all of the processing in an FFT or DFT technique may be performed in the digital domain with the aid of the 2-channel high speed ADC 1780, 1800, for example. In one technique, the digital signal samples of the voltage and current signals are Fourier transformed with an FFT or a DFT. The phase angle φ at any point in time can be calculated by:

[0258] $\varphi = 2\pi f t + \varphi_0$

[0259] Where φ is the phase angle, f is the frequency, t is time, and φ_0 is the phase at t = 0.

[0260] Another technique for determining the phase difference between the voltage $V_g(t)$ and current $I_g(t)$ signals is the zero-crossing method and produces highly accurate results. For voltage $V_g(t)$ and current $I_g(t)$ signals having the same frequency, each negative to positive zero-crossing of voltage signal $V_g(t)$ triggers the start of a pulse, while each negative to positive zero-crossing of current signal $I_g(t)$ triggers the end of the pulse. The result is a pulse train with a pulse width proportional to the phase angle between the voltage signal and the current signal. In one aspect, the pulse train may be passed through an averaging filter to yield a measure of the phase difference. Furthermore, if the positive to negative zero crossings also are used in a similar manner, and the results averaged, any effects of DC and harmonic components can be reduced. In one implementation, the analog voltage $V_g(t)$ and current $I_g(t)$ signals are converted to digital signals that are high if the analog signal is positive and low if the analog signal is negative. High accuracy phase estimates require sharp transitions between high and low. In one aspect, a Schmitt trigger along with an RC stabilization network may be employed to convert the analog signals into digital signals. In other aspects, an edge triggered RS flip-flop and ancillary circuitry may be employed. In yet another aspect, the zero-crossing technique may employ an eXclusive OR (XOR) gate.

[0261] Other techniques for determining the phase difference between the voltage and current signals include Lissajous figures and monitoring the image; methods such as the three-voltmeter method, the crossed-coil method, vector voltmeter and vector impedance methods; and using phase standard instruments, phase-locked loops, and other techniques as described in Phase Measurement, Peter O'Shea, 2000 CRC Press LLC, <http://www.engnetbase.com>, which is incorporated herein by reference.

[0262] In another aspect, for example, the current feedback data may be monitored in order to maintain the current amplitude of the drive signal at a current amplitude setpoint. The current amplitude setpoint may be specified directly or determined indirectly based on specified voltage amplitude and power setpoints. In certain aspects, control of the current amplitude may be implemented by control algorithm, such as, for example, a proportional-integral-derivative (PID) control algorithm, in the processor 1740. Variables controlled by the control algorithm to suitably control the current amplitude of the drive signal may include, for example, the scaling of the LUT waveform samples stored in the programmable logic device 1660 and/or the full-scale output voltage of the DAC 1680 (which supplies the input to the power amplifier 1620) via a DAC 1860.

[0263] The non-isolated stage 1540 may further comprise a processor 1900 for providing, among other things, user interface (UI) functionality. In one aspect, the processor 1900 may

comprise an Atmel AT91 SAM9263 processor having an ARM 926EJ-S core, available from Atmel Corporation, San Jose, Calif., for example. Examples of UI functionality supported by the processor 1900 may include audible and visual user feedback, communication with peripheral devices (e.g., via a Universal Serial Bus (USB) interface), communication with a foot switch 1430, communication with an input device 2150 (e.g., a touch screen display) and communication with an output device 2140 (e.g., a speaker). The processor 1900 may communicate with the processor 1740 and the programmable logic device (e.g., via a serial peripheral interface (SPI) bus). Although the processor 1900 may primarily support UI functionality, it may also coordinate with the processor 1740 to implement hazard mitigation in certain aspects. For example, the processor 1900 may be programmed to monitor various aspects of user input and/or other inputs (e.g., touch screen inputs 2150, foot switch 1430 inputs, temperature sensor inputs 2160) and may disable the drive output of the generator 1100 when an erroneous condition is detected.

[0264] FIG. 21 illustrates a generator circuit 3500 partitioned into multiple stages where a first stage circuit 3504 is common to the second stage circuit 3506, in accordance with at least one aspect of the present disclosure. In one aspect, the surgical instruments of surgical system 1000 described herein may comprise generator circuit 3500 partitioned into multiple stages. For example, the surgical instruments of surgical system 1000 may comprise the generator circuit 3500 partitioned into at least two circuits: the first stage circuit 3504 and the second stage circuit 3506 of amplification enabling operation of high-frequency (RF) energy only, ultrasonic energy only, and/or a combination of RF energy and ultrasonic energy. A combination modular shaft assembly 3514 may be powered by a common first stage circuit 3504 located within the handle assembly 3512 and a modular second stage circuit 3506 integral to the modular shaft assembly 3514. As previously discussed throughout this description in connection with the surgical instruments of surgical system 1000, a battery assembly 3510 and the shaft assembly 3514 are configured to mechanically and electrically connect to the handle assembly 3512. The end effector assembly is configured to mechanically and electrically connect the shaft assembly 3514.

[0265] As shown in the example of FIG. 21, the battery assembly 3510 portion of the surgical instrument comprises a first control circuit 3502, which includes the control circuit 3200 previously described. The handle assembly 3512, which connects to the battery assembly 3510, comprises a common first stage drive circuit 3420. As previously discussed, the first stage drive circuit 3420 is configured to drive ultrasonic, high-frequency (RF) current, and sensor loads. The output of the common first stage drive circuit 3420 can drive any one of the second stage circuits 3506 such as the second stage ultrasonic drive circuit 3430, the second stage high-frequency (RF) current drive circuit 3432, and/or the second stage sensor drive circuit 3434. The common first stage drive circuit 3420 detects which second stage

circuit 3506 is located in the shaft assembly 3514 when the shaft assembly 3514 is connected to the handle assembly 3512. Upon the shaft assembly 3514 being connected to the handle assembly 3512, the common first stage drive circuit 3420 determines which one of the second stage circuits 3506 (e.g., the second stage ultrasonic drive circuit 3430, the second stage RF drive circuit 3432, and/or the second stage sensor drive circuit 3434) is located in the shaft assembly 3514. The information is provided to the control circuit 3200 located in the handle assembly 3512 in order to supply a suitable digital waveform to the second stage circuit 3506 to drive the appropriate load, e.g., ultrasonic, RF, or sensor. It will be appreciated that identification circuits may be included in various assemblies 3516 in third stage circuit 3508 such as the ultrasonic transducer 1120, the electrodes 3074a, 3074b, or the sensors 3440. Thus, when a third stage circuit 3508 is connected to a second stage circuit 3506, the second stage circuit 3506 knows the type of load that is required based on the identification information.

[0266] FIG. 22 illustrates a diagram of a surgical system 4000, which represents one aspect of the surgical system 1000, comprising a feedback system for use with any one of the surgical instruments of surgical system 1000, which may include or implement many of the features described herein. The surgical system 4000 may include a generator 4002 coupled to a surgical instrument that includes an end effector 4006, which may be activated when a clinician operates a trigger 4010. In various aspects, the end effector 4006 may include an ultrasonic blade to deliver ultrasonic vibration to carry out surgical coagulation/cutting treatments on living tissue. In other aspects the end effector 4006 may include electrically conductive elements coupled to an electrosurgical high-frequency current energy source to carry out surgical coagulation or cauterization treatments on living tissue and either a mechanical knife with a sharp edge or an ultrasonic blade to carry out cutting treatments on living tissue. When the trigger 4010 is actuated, a force sensor 4012 may generate a signal indicating the amount of force being applied to the trigger 4010. In addition to, or instead of a force sensor 4012, the surgical instrument may include a position sensor 4013, which may generate a signal indicating the position of the trigger 4010 (e.g., how far the trigger has been depressed or otherwise actuated). In one aspect, the position sensor 4013 may be a sensor positioned with an outer tubular sheath or reciprocating tubular actuating member located within the outer tubular sheath of the surgical instrument. In one aspect, the sensor may be a Hall-effect sensor or any suitable transducer that varies its output voltage in response to a magnetic field. The Hall-effect sensor may be used for proximity switching, positioning, speed detection, and current sensing applications. In one aspect, the Hall-effect sensor operates as an analog transducer, directly returning a voltage. With a known magnetic field, its distance from the Hall plate can be determined.

[0267] A control circuit 4008 may receive the signals from the sensors 4012 and/or 4013. The control circuit 4008 may include any suitable analog or digital circuit components. The control circuit 4008 also may communicate with the generator 4002 and/or a transducer 4004 to modulate the power delivered to the end effector 4006 and/or the generator level or ultrasonic blade amplitude of the end effector 4006 based on the force applied to the trigger 4010 and/or the position of the trigger 4010 and/or the position of the outer tubular sheath described above relative to a reciprocating tubular actuating member located within an outer tubular sheath (e.g., as measured by a Hall-effect sensor and magnet combination). For example, as more force is applied to the trigger 4010, more power and/or higher ultrasonic blade amplitude may be delivered to the end effector 4006. According to various aspects, the force sensor 4012 may be replaced by a multi-position switch.

[0268] According to various aspects, the end effector 4006 may include a clamp or clamping mechanism. When the trigger 4010 is initially actuated, the clamping mechanism may close, clamping tissue between a clamp arm and the end effector 4006. As the force applied to the trigger increases (e.g., as sensed by force sensor 4012) the control circuit 4008 may increase the power delivered to the end effector 4006 by the transducer 4004 and/or the generator level or ultrasonic blade amplitude brought about in the end effector 4006. In one aspect, trigger position, as sensed by position sensor 4013 or clamp or clamp arm position, as sensed by position sensor 4013 (e.g., with a Hall-effect sensor), may be used by the control circuit 4008 to set the power and/or amplitude of the end effector 4006. For example, as the trigger is moved further towards a fully actuated position, or the clamp or clamp arm moves further towards the ultrasonic blade (or end effector 4006), the power and/or amplitude of the end effector 4006 may be increased.

[0269] According to various aspects, the surgical instrument of the surgical system 4000 also may include one or more feedback devices for indicating the amount of power delivered to the end effector 4006. For example, a speaker 4014 may emit a signal indicative of the end effector power. According to various aspects, the speaker 4014 may emit a series of pulse sounds, where the frequency of the sounds indicates power. In addition to, or instead of the speaker 4014, the surgical instrument may include a visual display 4016. The visual display 4016 may indicate end effector power according to any suitable method. For example, the visual display 4016 may include a series of LEDs, where end effector power is indicated by the number of illuminated LEDs. The speaker 4014 and/or visual display 4016 may be driven by the control circuit 4008. According to various aspects, the surgical instrument may include a ratcheting device connected to the trigger 4010. The ratcheting device may generate an audible sound as more force is applied to the trigger 4010, providing an indirect indication of end effector power. The surgical instrument may include other features that may enhance safety. For example, the control circuit 4008 may be

configured to prevent power from being delivered to the end effector 4006 in excess of a predetermined threshold. Also, the control circuit 4008 may implement a delay between the time when a change in end effector power is indicated (e.g., by speaker 4014 or visual display 4016), and the time when the change in end effector power is delivered. In this way, a clinician may have ample warning that the level of ultrasonic power that is to be delivered to the end effector 4006 is about to change.

[0270] In one aspect, the ultrasonic or high-frequency current generators of the surgical system 1000 may be configured to generate the electrical signal waveform digitally such that the desired using a predetermined number of phase points stored in a lookup table to digitize the wave shape. The phase points may be stored in a table defined in a memory, a field programmable gate array (FPGA), or any suitable non-volatile memory.

Advanced Energy Device Control Algorithms

[0271] Various control algorithms for ultrasonic surgical instruments and combination energy surgical instruments (e.g., ultrasonic/monopolar surgical instruments, monopolar/bipolar surgical instruments, ultrasonic/bipolar surgical instruments, and other such combination energy devices) are described herein. For the sake of clarity, surgical instruments will be referenced as surgical instrument 7012 in this section of the present disclosure, although the disclosure of this section could also apply to other surgical instruments referenced above such as surgical instrument 112, 700.

[0272] In various aspects, a control algorithm for an ultrasonic surgical instrument 7012 can be configured to apply a variable clamp arm pressure over the cycle time or the tissue coagulation/cut process of a surgical operation to create a constant proximal-to-distal pressure profile. The constant pressure profile means that each portion of tissue held within the end effector of surgical instrument 7012 along the proximal to distal end of the end effector experiences the same or substantially same pressure resulting from the force applied by the end effector clamp arm. This may advantageously result in better coagulation of surgically cut tissue. The control algorithm can be applied by a control circuit and/or a surgical hub. The constant proximal-to-distal pressure profile may involve applying the control algorithm to vary the pressure applied by the clamp arm to provide a threshold control pressure at the cut progression location. The cut progression location can be represented by the progression of a corresponding weld/coagulation focal point determined by the control circuit and/or surgical hub. Thus, the pressure may be varied based on the focal point. The threshold control pressure may be a constant pressure applied to the tissue regardless of the amount of the end effector that is active. That is, the applied pressure does

not change (or at least does not significantly change) despite any changes in the extent of tissue loading of the end effector.

[0273] A tissue bite or portion of tissue may be loaded into the end effector for surgical treatment, such as by loading the distal end of the end effector with tissue first. In this way, contact may initially be made at a distal point of the end effector. A distal portion of one or more of the ultrasonic blade and clamp arm could grasp the tissue at this distal point. The initial pressure applied by the clamp arm may be determined or adjusted (e.g., from a default pressure level) by a control circuit and/or surgical hub based on the size of the tissue bite initially being grasped, which corresponds to an amount of the blade being utilized at the start (an initial tissue loading of the end effector). After surgical cutting of tissue, surgical coagulation/sealing may be performed by the surgical instrument 7012, such as by ultrasonic vibration of the ultrasonic blade and/or delivery of an RF electrical signal waveform output from the generator to RF electrodes. In the coagulation process, the progression of the weld may be used to adjust the applied clamp pressure. Specifically, the pressure of the clamp arm can adjust over the progression of the weld as the cut/weld focal point shifts along the blade.

[0274] In order to better grasp the tissue at the distal point, one or more of the blade and clamp arm could be biased or offset to create a preferential initial contact point at the distal end. Subsequently, the remaining portion of the clamp arm may then be broadly loaded in a distal to proximal manner. Stated differently, in this distal start closure stroke configuration, the offset ultrasonic blade may deflect so as to fully close against the tissue and clamp arm fully at the end effector distal end followed by deflecting further in the proximal direction. The deflections of the blade and clamp arm may be approximately equal or balanced relative to each other. The distal start closure stroke configuration is described in more detail below. The clamp arm pressure can also be varied from the initial pressure by the control circuit and/or surgical hub based on the degree that the end effector is loaded with the tissue and the progression through the weld. Also, the clamp arm pressure can be varied based on the measured tissue impedance (e.g., via a pressure, resistive, or other suitable sensor 788 in the end effector). Moreover, depending on which energy modality or modalities of the surgical instrument 7012 are selected, the power level of one or more of RF and ultrasonic energy delivered to the end effector can also be varied based on the measured tissue impedance. Other types of electrosurgical energy besides RF and ultrasonic energy could also be used.

[0275] As discussed above, the tissue loading might commence at the tip or distal end of the end effector such that the first contact between the ultrasonic blade and the clamp arm is at the tip. The surgical hub and/or control circuit can be configured to vary pressure applied by the clamp arm based on the extent of blade utilization, which could be determined via

position sensor 784 (referred to in this portion of the present disclosure as position sensor 784, although position sensor 784 may also refer to position sensor 734, 4013 or others as described above). In particular, the application of clamp pressure can be controlled so that the clamp arm and ultrasonic blade do not apply pressure at portions of the end effector that do not contain tissue. In other words, the application of clamp pressure is tailored to those portions of the end effector in which tissue is located between the ultrasonic blade and clamp arm. This may advantageously reduce temperatures and heat residing in the ultrasonic blade after activation of the generator of the surgical instrument 7012. To elaborate further, when the generator delivers energy to the end effector, the portions of the end effector in which tissue is not located receive a relatively lower force so energy delivered to these portions is reduced. Consequently, after activating the generator, the peak temperatures and heat of the ultrasonic blade are reduced.

[0276] This targeted application of force by the clamp arm can be achieved based on motorized or manual closure control, tip first closure of the end effector, and feedback provided to the control circuit and/or surgical hub. The feedback could include thermally induced changes in the resonant frequency and electrical continuity (or discontinuity). The feedback could be received by the control circuit via circuitry that comprises the ultrasonic blade and a clamp arm/ultrasonic blade interface (e.g., clamp tissue pad). The changes or shift in the resonant frequency of the transducer may be used as feedback to determine the extent of the tissue loading. In this way, the feedback may be used to adjust applied clamp pressure. Furthermore, the control circuit may control the motor of the surgical instrument to implement the closure stroke so that the end effector closes at a point which is distal to the proximal-most point of the grasped tissue. In this way, a gap may be maintained between the clamp arm and ultrasonic blade at a point which is proximal to the proximal-most point of the grasped tissue.

[0277] Sensors 788 (referenced as sensors 788 in this portion of the present disclosure, although they could also refer to sensors 738 or other sensors described above) of the surgical instrument 7012 may provide end effector closure signals as input to the control circuit. Using this input, the control circuit can determine the current closure position of the end effector. When the control circuit determines that the end effector is merely closed at the tip portions (e.g., distal tip or proximal tip) or at some other sub-portion of the end effector length (e.g., the distal half of the end effector), the control circuit may reduce displacement of the ultrasonic blade. To this end, power provided to the ultrasonic transducer may be reduced. This reduction in displacement might beneficially prevent or reduce excessive wear of the clamp arm tissue pad at the distal tip. This excessive wear generally is caused by high distal forces or pressure at the distal tip (corresponding to the distal start closure stroke

configuration) and inherent high distal displacement corresponding to displacement profiles associated with ultrasonic blades.

[0278] In general, when the tissue does not fully occupy the space between the jaws of the end effector, reducing the surface area of the clamp arm being compressed against the blade reduces the wasteful transmission of electrosurgical energy (e.g., including ultrasonic and RF energy) to the clamp arm and/or tissue pad. In other words, the adjustment in clamp arm pressure enables relatively more electrosurgical energy to be directed towards the tissue rather than undesirably being transmitted to other parts of the end effector. Because the pressure applied by the clamp arm is controlled based on the extent of tissue loading, a constant pressure may be applied to the tissue regardless of how much of the end effector is in an active state. The pressure may further be adjusted based on progression of the surgical coagulation/cutting treatment by the surgical instrument 7012.

[0279] Furthermore, the feedback circuitry comprising the ultrasonic blade and clamp pad can also comprise sensor 788 for sensing impedance of the tissue located between the clamp arm and the ultrasonic blade. In this case, the ultrasonic blade and associated waveguide that terminates at the blade could serve as part of the return path for the feedback circuitry. The sensed impedance can indicate a status of the coagulation/cut cycle. That is, for example, comparing the tissue impedance to a threshold may be indicative of a weld progression of the tissue, such as a progression of the weld/coagulation focal point. The focal point may be ndicative of how well formed a fibrin clot is for coagulation, for example. In this way, the detected tissue impedance can enable the control circuit and/or surgical hub to adjust power provided to the ultrasonic transducer and the force applied by the clamp arm.

[0280] Although at least some portion of the control algorithm(s) disclosed herein can be performed by surgical hubs (alone or in conjunction with associated control circuits of surgical instruments), the functions of the control algorithm(s) are described as performed by control circuits for the sake of clarity. Also for clarity, the control circuit of surgical instrument 7012 in this portion of the present disclosure is labeled control circuit 710, although control circuit 710 can be the same or similar to control circuits 760, 3200, 3502, 4008. Control circuit 710 may be a part of the generator 4002 itself (referred to as generator 4002 for clarity although generator 4002 can be the same or similar to generator 140, 145, 240, 721, 771, 900, 1100) or another part of the surgical instrument 7012 that is remote from the generator 4002. In various aspects, the surgical instrument 7012 (e.g, ultrasonic surgical instrument) as described in FIGS. 23A-23B, 24A-24B, 25-26, 27A-27C, 28A-28C, 29A-29C, 30A-30D, 31A-31D, 32A-32E, is configured to operate with situational awareness in a hub environment, such as the surgical hub 106 or 206 (FIGS. 1–11), for example, as depicted by the timeline 5200.

[0281] FIG. 23A-23B are graphs 203000, 203020 including a graph of clamp force as a function of time and an associated graph of a coagulation/cut focal point, in accordance with at least one aspect of the present disclosure. In FIG. 23A, the y-axis 203010 denotes force while the x-axis 203008 denotes time. The dashed line 203002 represents the force applied by the clamp arm over time and tracks the application of force by the clamp arm from the minimum force at time t_0 to maximum force at time t_{10}. Clamp force may be measured in suitable units, such as pounds (lbs). The time spanning initial time t_0 to time t_{10} can define a surgical cycle of the surgical instrument 7012. The dash-and-dot line 203004 represents the measured tissue impedance over the surgical cycle. As can be seen on graph 203000, the measured tissue impedance decreases from its initial level at time t_0 to the low point at time t_3, demonstrating the drop in impedance resulting from the commencement of surgical treatment (the so-called "bathtub" portion of the impedance curve). After time t_3, the tissue impedance line 203004 rises as the tissue being treated begins to dry out. This desiccation results in an increase in tissue impedance. FIG. 23A shows how this increase in tissue impedance line 203004 corresponds to an increase in the applied force line 203002. The increase in applied force may assist in cutting the tissue and welding the denatured tissue as the surgical cycle is completed.

[0282] In particular, the control circuit 710 may execute the control algorithm to provide a constant proximal-to-distal pressure profile. By providing such a threshold control pressure, the tissue seal formed during the coagulation stage advantageously may be more uniform and secure. Accordingly, the solid line 203006, which indicates a measured pressure applied to the tissue in the end effector, stays the same or roughly constant throughout the surgical cycle. The tissue pressure line 203006 may correspond to the pressure applied at the leading edge of the end effector, where surgical coagulation and cutting occur. Clamp force can be a function of the progress of the tissue coagulation process. This relationship may be used to provide the constant tissue pressure. Thus, while tissue may be coagulated and cut at the proximal sections of the end effector, increasing clamp force at the distal section results in better coupling of the tissue to the distal sections of the ultrasonic blade. In this way, each section of tissue (which spans the proximal to distal sections of the end effector) could experience the same or approximately similar pressure. As the tissue weld progresses, the control circuit may control the clamp arm to progressive closure, which is demonstrated by graph 203000. Also, the clamp arm may be cambered to the ultrasonic wave guide that terminates into the ultrasonic blade.

[0283] FIG. 23B shows that the focal point of the surgical coagulation and cutting operation on the tissue shifts along the length of ultrasonic blade 203026 (similar to or the same as ultrasonic blade 718, 768 or other ultrasonic blades described above) over the course of the surgical cycle. As shown in FIG. 23B, the focal point shifts in a proximal to

distal direction over time, but the focal point could also shift in a distal to proximal direction. The former possibility corresponds to a proximal start closure stroke configuration while the latter corresponds to a distal start closure stroke configuration. As discussed above, the control circuit 710 may be configured to determine the cut/weld focal point based on one or more of the resonant frequency and electrical continuity feedback measures. Graph 203020 also portrays clamp arm 203022 (similar to the same as clamp arm 716, 766 or other clamp arms described above). Clamp arm 203022 can comprise clamp tissue pad 203024, which may be formed from TEFLON® or some other suitable low-friction material. The pad 203024 may be mounted for cooperation with the blade 203026, with pivotal movement of the clamp arm 203022 positioning the clamp pad 203024 in substantially parallel relationship to, and in contact with, the ultrasonic blade 203026. By this construction, a tissue bite to be clamped may be grasped between the tissue pad 203024 and the ultrasonic blade 203026. The tissue pad 203024 may be provided with a sawtooth-like configuration including a plurality of axially spaced, proximally extending gripping teeth to enhance the gripping of tissue in cooperation with the ultrasonic blade 203026. The control circuit 710 may control the clamp arm 203022 to transition from between an open position and a closed position, including various intermediate positions in between. The control circuit 710 may vary the pressure applied by the clamp arm 203022 based on a shift in the weld focal point along the ultrasonic blade 203026 or an extent of tissue loading in the end effector.The x-axis 203028 of graph 203020 represents the surgical cycle in the same manner that x-axis 203008 does.

[0284] FIGS. 24A-24B are graphs 203040, 203060 including a graph 203040 of clamp force as a function of distance from the distal tip of the end effector and a graph 203060 of blade displacement as a function of distance from the distal tip, in accordance with at least one aspect of the present disclosure. FIG. 24A illustrates how the clamp pressure between the ultrasonic blade 203026 and clamp arm 203022 varies as a function of the distance from the distal tip relative to the tissue. Specifically, the graph 203040 includes a plurality of clamp pressure curves 203042A-203042D showing how the control circuit 710 can adjust the applied clamp pressure depending on the position of the tissue. To this end, the control circuit 710 may determine the closure position of one or more of the ultrasonic blade 203026 and clamp arm 203022. The x-axis 203044, 203064 denotes distance from the distal tip of the end effector while the y-axis 203046, 203066 denotes applied clamp force. In the proximal start closure stroke configuration of FIG. 24A, the applied clamp pressure rolls in a distal direction during the closure motion so that the closure stroke is at the fully clamped state at the distal tip. Put differently, the clamp pressure may be maximal when the distance from the distal tip is minimal. High amplitude of clamp pressure may be necessarily to surgically manipulate the tissue such as manipulating the structure of a blood vessel as desired.

[0285] FIG. 24B illustrates the corresponding displacement profile of the ultrasonic blade 203026 as a function of distance from the tip of the end effector. In the graph 203060, the x-axis 203064 again denotes distance from the distal tip while the y-axis 203066 denotes the magnitude of displacement of the ultrasonic blade 203026. Relatedly, the zero point of the x-axis corresponds an anti-node 203062 while the maximal point corresponds to a node 203068 of the ultrasonic blade 203026. The anti-node 203062 can be defined as a local absolute maximum in which the displacement or vibration of the ultrasonic blade 203026 is maximal. The node 203068 can be defined as a local absolute minimum in which the displacement or vibration of the ultrasonic blade 203026 is minimal. In general, the distance between the adjacent node and anti-nodes can be one-quarter wavelength of the drive or resonant frequency of the ultrasonic blade 203026. As illustrated by the graph 203060, at the anti-node 203062, the occurrence of the positive maximum extent of ultrasonic vibration of the ultrasonic blade 203026 overlaps with the maximal distance away from the distal tip. This would also occur at the next anti-node corresponding to the negative maximum extent of ultrasonic vibration, although this is not shown in FIG. 24B. At the point (node 203068) of minimum distance away from the distal tip, the ultrasonic vibration is minimal so as to fully clamp or grasp tissue between the ultrasonic blade 203026 and clamp arm 203022. This change in ultrasonic displacement as a function of distance of tip is represented by displacement line 203070.

[0286] In contrast to the proximal start closure stroke configuration, the present disclosure may contemplate a distal start closure stroke configuration in which first closing the distal tip of the end effector ultimately assists in advantageously attaining heat mitigation. Heat mitigation can occur by configuring the control circuit 710 to control clamp pressure according to the extent of tissue loading in the end effector. Specifically, pressure may be provided only at points of intersection where ultrasonic blade 203026 and clamp arm 203022 grasp tissue therebetween. By preventing or reducing pressure at portions of the end effector where no tissue resides, peak temperatures and residual heat after energy delivery from the generator 4002 are reduced. In this way, relatively more energy is transmitted to the tissue instead of the electrically conductive clamp arm tissue pad 203024. The clamp pad 203024 may be formed of a molded, carbon filled polytetraflouroethylene or some other suitable material and additionally may be secured to the underside of clamp arm 203022, as described in U.S. Publication No. 2017/0164997, titled METHOD OF TREATING TISSUE USING END EFFECTOR WITH ULTRASONIC AND ELECTROSURGICAL FEATURES, published on June 15, 2017, which is herein incorporated by reference in its entirety.

[0287] Also, the clamp tissue pad 203024 may be electrically conducive based on the use of conductive fillers (e.g. carbon, carbon nanotubes, metallic particles, etc.). Electrical current could flow through the surgical instrument 7012 from the ultrasonic blade 203026 to

the tissue pad 203024 via isolated electrical circuitry, which enables the application of therapeutic or sub-therapeutic RF energy to the tissue by the end effector (e.g., via RF electrode 796). When the surgical instrument 7012 includes RF electrode 796, the control circuit 710 can be configured to adjust one or more of a power level of the RF energy and a power level of the electrosurgical energy based on determined tissue impedance. More details regarding conductive pads may be found in U.S. Patent No. 9,764,164, titled ULTRASONIC SURGICAL INSTRUMENTS, issued on September 19, 2017, which is herein incorporated by reference in its entirety. Other aspects of combination bipolar RF and ultrasonic architectures of surgical instrument 7012 are described in U.S. Patent No. 9,017,326, titled IMPEDANCE MONITORING APPARATUS, SYSTEM, AND METHOD FOR ULTRASONIC SURGICAL INSTRUMENTS, issued on April 28, 2015; U.S. Patent No. 10,022,568, titled DEVICES AND TECHNIQUES FOR CUTTING AND COAGULATING TISSUE, issued on July 17, 2018; and U.S. Publication No. 2017/0164997, titled METHOD OF TREATING TISSUE USING END EFFECTOR WITH ULTRASONIC AND ELECTROSURGICAL FEATURES, published on June 15, 2017, all of which are herein incorporated by reference in their entirety.

[0288] The control circuit 710 may control the motor of the surgical instrument 7012 to adjust the closure of the clamp arm 203022 and/or the movement of the ultrasonic blade 203026 for heat mitigation and energy efficiency. To this end, only a part of the full length of the end effector could be used to grasp and treat tissue. For example, only the distal end of the end effector could initially close on a tissue bite followed by progressively more tissue loading in the proximal direction. In this distal start closure stroke configuration, the applied force by the clamp arm is increased until reaching the full closure stroke threshold while the clamp arm 203022 and/or ultrasonic blade 203026 gradually deform to fully compress against tissue while maintaining a slight gap therebetween in portions of the end effector that do not contain tissue. When the full closure stroke of the end effector is attained, the clamp tissue pad 203024 may contact the entire length of the tissue treating portion of the ultrasonic blade 203026. In this way, the control circuit can be configured to close the end effector at a distal end of the end effector prior to closing non-distal end portions of the end effector. The pressure profile of the tissue treating or end effecting portion of the ultrasonic blade 203026 is described in more detail below.

[0289] An offset, sloping, or otherwise curved ultrasonic blade 203026 can assist in facilitating distal tip first closure of the clamp arm 203022. More detail regarding closing the distal tip of the end effector first (distal start closure stroke configuration) and the offset ultrasonic blade 203026 may be found in U.S. Patent No. 8,444,663, titled ULTRASONIC SURGICAL SHEARS AND TISSUE PAD FOR THE SAME, issued on May 21, 2013; U.S. Patent No. 10,004,527, titled ULTRASONIC SURGICAL INSTRUMENT WITH STAGED

CLAMPING, issued on June 26, 2018; U.S. Publication No. 2018/0153574, titled HEADPIECE AND BLADE CONFIGURATIONS FOR ULTRASONIC SURGICAL INSTRUMENT, published on June 7, 2018; U.S. Publication No. 2018/0153574, titled HEADPIECE AND BLADE CONFIGURATIONS FOR ULTRASONIC SURGICAL INSTRUMENT, issued on June 7, 2018; and U.S. Publication No. 2018/0014848, titled ULTRASONIC SURGICAL INSTRUMENTS HAVING OFFSET BLADES, published on January 18, 2018, all of which are herein incorporated by reference in their entirety. As discussed above, the ultrasonic blade 203026 and/or clamp arm 203022 may be compliant so that the control circuit 710 causes the ultrasonic blade 203026 and/or clamp arm 203022 to deform as the applied clamp force increases. FIGS. 32A-32E illustrate how this deformation may occur as tissue treatment proceeds. In general, the end effector should be in a full closure state prior to application of electrosurgical energy. Also, a first deflection of the offset ultrasonic blade can correspond to a second deflection of the offset clamp arm. The first and second deflection could be shaped according to a closure pressure profile implemented by the control circuit 710 to provide relatively greater pressure in the proximal portion of the end effector.

[0290] The control circuit 710 may use feedback to control the end effector for heat mitigation as described above. For example, the control circuit 710 could monitor the resonant frequency of the ultrasonic blade 203026. In particular, the generator 4002 may include a tuning inductor for tuning out the static capacitance at a resonant frequency so that substantially all of generator's current output flows into the motional branch. The motional branch current, along with the drive voltage, define the impedance and phase magnitude. Accordingly, the current output of the generator 4002 represents the motional branch current, thus enabling the generator 4002 to maintain its drive output at the ultrasonic transducer's resonant frequency. The control circuit 710 can monitor drive signals of the generator 4002 that correlate to the resonant frequency. The generator 4002 may deliver electrosurgical energy to the end effector to weld tissue based on generating the drive signal. As a surgical treatment cycle proceeds, the resonant frequency changes due to changes in the material stiffness of the tissue. In turn, the change in material stiffness occurs because of the rapid accumulation of thermal energy in the ultrasonic blade 203026, as electrosurgical energy is being delivered.

[0291] The control circuit 710 is configured to evaluate this dynamic thermal response via frequency changes or frequency slope (e.g., first derivative of frequency or frequency change with respect to time), such as based on comparison to a frequency threshold parameter value. Additionally or alternatively, the control circuit 710 can compare the change in resonant frequency relative to an initial frequency value determined at the start of electrosurgical energy activation, which can be recorded to the memory of the surgical

instrument 7012. Based on electrical signals generated by the generator 4002, the control circuit 710 may determine and compare frequency slope or frequency changes against corresponding thresholds. Specifically, the control circuit 710 may determine: (i) when the frequency slope is above the associated threshold parameter value and (ii) when the frequency change is above a frequency floor. Above a frequency floor means, for example, that the drop in frequency does not exceed a predetermined threshold drop relative to the determined initial frequency value. Based on one or more of these determinations, the control circuit 710 (e.g., via the motor) can control the ultrasonic blade 203026 and/or clamp arm 203022 to reduce closure force/stroke when the frequency monitoring conditions (i), (ii) are met. As such, the control circuit 710 may determine a resonant frequency measure indicative of a thermally induced change in resonant frequency to calculate a tissue weld/seal focal point.

[0292] In this way, the control circuit 710 causes the applied clamp force or pressure to "back off", to beneficially minimize the delivery of thermal energy to the clamp pad 203024 at locations that are proximal to the proximal extent of the grasped tissue. More details regarding resonant frequency monitoring can be found in U.S. Patent No. 8,512,365, titled SURGICAL INSTRUMENTS, issued August 20, 2013; and U.S. Patent No. 9,788,851, titled SURGICAL INSTRUMENT WITH TISSUE DENSITY SENSING, issued on October 17, 2017; both of which are herein incorporated by reference in their entirety. Furthermore, the control circuit 710 can be programed to follow a set limit defining the permissible extent to which the control circuit 710 backs off on closure force or stroke. The set limit could be determined in order to prevent tissue from slipping out or otherwise escaping from the grasp of the end effector. In addition, the surgical instrument 7012 could be designed to provide user feedback such as visual, audible, tactile, haptic, vibratory, or some other feedback to the user that is indicative of the current closure state. For example, the user feedback (e.g., light emitting diode, graphical user interface, buzzer, computer generated sound, handle vibration etc.) might indicate when the end effector closes at a point proximal the proximal extent of the grasped tissue. In situations where the user selects an override setting for overriding the automatic closure control feature of the surgical instrument 7012, this user feedback can be particularly helpful to inform the user of closure status.

[0293] As another example of feedback, the control circuit 710 could monitor the electrical impedance of the surgical instrument 7012. In various aspects, the surgical instrument 7012 may conduct electrical current between the ultrasonic blade 203026 and the clamp arm tissue pad 203024 for delivery of electrosurgical energy. By monitoring this electrical current (or lack thereof), tissue impedance, or transducer impedance based on an end effector sensor 788 and/or drive signal of generator 4002, the control circuit 710 may determine the amount of tissue loading in the end effector. In particular, the control circuit 710 may be

programmed to detect and maintain an impedance of the circuit comprising the blade 203026 and the clamp arm tissue pad 203024 above a predetermined threshold. This maintained impedance can correspond or approximately correspond to an electrical short. As such, the electrical short means electrical discontinuity exists between the ultrasonic blade 203026 and the clamp arm tissue pad 203024. Therefore, minimal thermal energy is delivered to the portion of the clamp arm tissue pad 203024 located proximally to the proximal extent of the grasped tissue. To arrive at this desired lack of electrical continuity, the control circuit 710 could perform the reduction or backing off of the closure force or stroke as described above. As such, the control circuit 710 may determine an electrical continuity measure to calculate a tissue weld/seal focal point.

[0294] On the other hand, when the end effector is not fully closed, the feedback received by the control circuit 710 may be used to reduce the output of the generator 4002. The output of the generator 4002 might be ultrasonic and/or bipolar RF electrosurgical energy, depending on the energy modality configuration of the surgical instrument 7012. By reducing the ultrasonic displacement of ultrasonic blade 203026 and/or RF power conducted via RF electrode 796, the control circuit 710 may prevent or lower instances of relatively high power densities at the distal tip of the end effector. This is especially true given that the ultrasonic vibration of ultrasonic blade 203026 is generally relatively high at the distal tip. In any case, avoiding these high power densities may advantageously stop or reduce excessive wearing or deterioration of the clamp arm tissue pad 203024. The acoustic drive impedance of the ultrasonic blade 203026 could also be used to assess jaw closure state. Additionally or alternatively, a closure switch of the surgical instrument 7012 such as a handle closure switch could indicate when the clamp arm 203022 and/or ultrasonic blade 203026 is closed, as described for example in U.S. Patent No. 9,724,118, titled TECHNIQUES FOR CUTTING AND COAGULATING TISSUE FOR ULTRASONIC SURGICAL INSTRUMENTS, issued on August 8, 2017, which is herein incorporated by reference in its entirety. Position sensor 734 or motor current also could be used to determine jaw closure state.

[0295] FIG. 25 is a graph 203080 of a clamp force distribution as a function of various sections along the length of the end effector, in accordance with at least one aspect of the present disclosure. The x-axis 203082 denotes a section along the length of the end effector, including section numbers 1 through 5. The y-axis 203084 denotes gradients of pressure measured in suitable units ranging from 1 through 4. The units could be pounds (lbs), for example. Section 1 represents the distal-most portion while section 4 represents the proximal-most portion of the end effector. The measured force can be determined by the control circuit 710 based on the sensor 788, such as a pressure sensor. The pressure output signal of pressure sensor 788 used to generate graph 203080 has been averaged or summed to smooth the clamp pressure line 203086. In other words, peaks and valleys in the

pressure line 203086 that might result from irregularities in the pad 203024 (e.g., teeth in the clamp pad 203024) or sensor 788 are softened or smoothed out in graph 203080. As illustrated by graph 203080, the force distribution in the proximal half of the end effector is relatively higher than the force distribution in the distal half of the end effector. In other words, the pressure profile ratio of the end effector is below the value 1.

[0296] The pressure profile ratio can be defined as the sum of pressure applied in the distal portion divided by the sum of pressure applied in the proximal portion of the end effector. Therefore, pressure profile ratios >1 indicate that the end effector is distal tip loaded while pressure profile ratios <1 indicate proximal loaded status. A distal tip loaded end effector may have more cumulative pressure on the distal half while a proximal loaded end effector has more cumulative pressure on the proximal half. As demonstrated by graph 203080, the end effector measured by pressure sensor 788 is proximally loaded. The proximally loaded status may be assessed from a position in which no tissue is contained within the end effector. One such example can be seen in FIG. 32A. The relatively higher force applied in the proximal portion of the end effector may result from the greater degree of curvature or offset between the ultrasonic blade 203026 and clamp arm 203022 in the distal portion relative to the proximal portion. Proximally loading the end effector may be desirable because the ultrasonic blade 203026 generally may ultrasonically vibrate to a greater extent towards to the distal portions. That is, the displacement of the ultrasonic blade 203026 might be greater at the distal portion than the proximal portion of the end effector. The relatively high clamp pressure applied at the proximal portion can advantageously ensure a more uniform application of electrosurgical energy to the tissue, thereby attaining a more secure cutting/coagulation surgical treatment.

[0297] FIG. 26 is a graph 203100 of blade displacement profile as a function of distance from the distal tip of the end effector, in accordance with at least one aspect of the present disclosure. The x-axis 203102 denotes distance from the distal tip of the end effector, which is shown in units of millimeters (mm) on graph 203100. The y-axis 203104 denotes the normalized velocity (on a scale ranging from 0 to 1) of the ultrasonic blade 203026. When normalized, the velocity profile as shown in 203100 is coterminous or overlaps with the displacement profile of the ultrasonic blade 203026. In addition, the driven resonant frequency 203108 of the ultrasonic blade 203026 defines the effective wavelength of the displacement or velocity profile. As shown in FIG. 26, the driven resonant frequency 203108 is 55.5 kilohertz (kHz), although other suitable resonant frequency values are possible as well. The driven resonant frequency 203108 is a factor of the material, geometry, and thermal condition of the surgical instrument 7012. Also shown in FIG. 26 is the tissue treatment border 203110 of the end effector. The tissue treatment border 203110 indicates the length of the tissue treating (e.g., cutting and coagulation) portion of the end effector and

is approximately 15 mm from the distal tip in graph 203100. The velocity-distance line 203106 represents the change in normalized velocity as a function of distance from the distal tip.

[0298] Stated another way, the tissue treating portion spans 15 mm from the distal tip of the end effector, as measured in the proximal direction. The velocity and/or displacement profile as portrayed in graph 203100 demonstrates that the velocity and/or displacement of the ultrasonic blade 203026 is maximal at the distal tip and decreases to the minimal value as the distance from the distal tip increases to the maximum. Accordingly, providing a preferential distribution of clamp force towards the proximal portion of the end effector as shown in FIG. 25, can allow for a more uniform power deposition along the length of the end effector. Power deposition is a function of the coefficient of friction, the velocity, and the applied force or pressure. Thus, as discussed above, matching the relatively high distal velocity to a relatively low distal pressure and matching the relatively low proximal velocity to a relatively high proximal pressure can result in more uniform cutting of tissue, as determined with respect to time. When the end effector is fully closed such that it has reached the full closure stroke, the resulting pressure or force profile is higher in the proximal half or quarter of the end effector, so graph 203080 shows how the pressure or force profile ratio is <1. Also, the deflections of the ultrasonic blade 203026 and clamp arm 203022 can be equivalent or match over the course of the closure stroke of the end effector.

[0299] FIGS. 27A-27C are sectional views of end effector 203120 that illustrate a closure stroke of the end effector, in accordance with at least one aspect of the present disclosure. The progression of the closure stroke as portrayed in FIGS. 27A-27C demonstrates a proximal start configuration closure stroke. In FIG. 27A, the end effector 203120 (which may be the same or similar to end effectors described above, including end effector 702, 752, 792, 4006) is at a more open position than in FIGS. 27B-27C. Clamp arm 203122 includes clamp arm tissue pad 203124, which may be the same or similar as pad 203024. In FIG. 27A, the clamp arm 203122 is spaced away from the ultrasonic blade 203126 so that clamp arm tissue pad 203124 initially begins to contact or touch the blade at the most proximal portion of the clamp arm tissue pad 203124. The clamp arm 203122 is sloped or angled upwards relative to a horizontal axis defined by the end effector 203120. Accordingly, the opening between the clamp arm 203122 and ultrasonic blade 203126 increases in the distal direction away from pivot point 203128. The clamp arm 203122 and ultrasonic blade 203126 may pivot about pivot point 203128.

[0300] Although FIG. 27A does not depict tissue grasped by the end effector 203120, in operation, tissue may be located in end effector 203120 such that the end effector 203120 compresses against tissue at the proximal-most extent of pad 203124 to being tissue treatment in FIG. 27A. In FIG. 27B, the clamp arm 203122 is further along in the closure

stroke of the end effector 203120. As such, most or all of the proximal portion of the end effector is in the closed position. Accordingly, FIG. 27B shows that the proximal-most extent of the pad 203124 contacts the ultrasonic blade 203126, while the portions of the pad 203124 immediately distal to the proximal-most extent are also almost closed or contacting the ultrasonic blade 203126. Again, the gap between the clamp arm 203122 and the ultrasonic blade 203126 increases in the distal direction away from pivot point 203128. FIG. 27C illustrates the full closure position of the end effector 203120. In FIG. 27C, the full extent of the clamp arm 203122 and pad 203124 contacts the ultrasonic blade 203126 to obtain the full closure stroke. Thus, clamp pressure is applied to all portions of the end effector 203120, as reflected in FIG. 28C. The closure progression of the proximal start configuration as depicted in FIGS. 27A-27C demonstrates how clamp pressure or force rolls in the distal direction.

[0301] FIGS. 28A-28C are graphs 203140, 203160, 203180 of clamp force applied between the blade and clamp arm as a function of distance from the distal tip of the end effector 203120 corresponding to the sectional views of FIGS. 27A-27C, in accordance with at least one aspect of the present disclosure. The applied clamp pressure or force plotted in graphs 203140, 203160, 203180 can be measured by pressure sensor 788. In the graphs 203140, 203160, 203180, the x-axis 203144, 203164, 203184 denotes the distance from the distal tip of end effector 203120. The y-axis 203146, 203166, 203186 denotes the clamp arm pressure or force applied between the clamp arm 203122 and the ultrasonic blade 203126. The applied clamp force line 203142, 203162, 203184 illustrates the clamp pressure as a function of distance from the distal tip of end effector 203120. As described above, the applied clamp pressure first begins at the proximal-most extent of clamp arm tissue pad 203124, adjacent to pivot point 203128. This is demonstrated by FIG. 28A. In FIG. 28B, the clamp pressure has begun to spread distally. Accordingly, the applied clamp force line 203162 starts at a more leftward point than that of applied clamp force line 203142. Moreover, the clamp pressure at the proximal-most extent of clamp arm tissue pad 20312 is greater in FIG. 28B than in FIG. 28A. That is, the amplitude at the rightmost portion of the applied clamp force line 203162 is greater than the corresponding amplitude of applied clamp force line 203142.

[0302] In FIG. 28C, the applied clamp force line 203182 starts at an even more leftward point than that of applied clamp force line 203162. In fact, clamp pressure is applied at all points spanning the x-axis 203184. The clamp pressure at the proximal-most extent of clamp arm tissue pad 20312 is greater in FIG. 28C than either of FIG. 28B and FIG. 28A. The graph 203180 of FIG. 28C illustrates the applied pressure in a full closure stroke or position of the end effector 203120. In the full closure state of the end effector 203120, it may be desirable for the control circuit 710 to implement computer executable logic or rules that

ensure the end effector 203120 reaches the full closure stroke prior to application of energy by the generator 4002. As discussed above, the full closure stroke is achieved when the end effector 203120 closes along its entire available length. By delivering electrosurgical energy to the tissue only after attaining the full closure position, better tissue sealing may be performed. In particular, homeostasis can be maximized or improved based on the full closure stroke laterally displacing the inner layers and approximating the outer layers of the tissue so that these layers may be joined during delivery of electrosurgical energy. That is, optimum vessel sealing may occur when the inner muscle layer of a vessel is separated and moved away from the adventitia layer prior to the application of electrosurgical energy. The outer tissue layers could form more reliable tissue welds or seals (e.g., tunica adventitia, serosal covering, etc.).

[0303] One example of such rules executed by the control circuit 710 includes a rule in which if the user activates the large vessel or advanced hemostasis mode of the surgical instrument 7012, the control circuit 710 verifies that the end effector 203120 has reaches the full closure stroke. This verification could occur via a handle closure or full closure switch of the surgical instrument 7012, for example. When the closure switch is not in the closed position, this indicates the end effector 203120 is not fully closed. Consequently, the surgical instrument 7012 may generate an alert such as an audible beeping sound or visual, audible, tactile, haptic, vibratory alert, or some other suitable alert. In some aspects, the surgical instrument 7012 may have mechanical components to control application of relatively high clamp force for displacing vessel structure (e.g., approximating adventitia) and of relatively low clamp force for energy delivery. More details regarding such rules and vessel structure manipulation for cutting and sealing tissue may be found in U.S. Patent No. 8,779,648, titled ULTRASONIC DEVICE FOR CUTTING AND COAGULATING WITH STEPPED OUTPUT, issued on July 15, 2014; U.S. Patent No. 9,241,728, titled SURGICAL INSTRUMENT WITH MULTIPLE CLAMPING MECHANISMS, issued on January 26, 2016; U.S. Patent No. 9,743,947, titled END EFFECTOR WITH A CLAMP ARM ASSEMBLY AND BLADE, issued on August 29, 2017; all of which are herein incorporated by reference in their entirety.

[0304] FIGS. 29A-29C are sectional views of the end effector 203200 that illustrate a proximal start closure stroke configuration, in accordance with at least one aspect of the present disclosure. As shown in FIG. 29A, the end effector 203200 starts in an open position in which clamp arm 203202 and ultrasonic blade 203206 define a relatively large gap in between each other. Clamp arm 203202 includes clamp arm tissue pad 203204, which may the same or similar as pad 203024, 203124. In FIG. 29B, the clamp arm 203202 has pivoted inwards with respect to pivot point 203208 so that the proximal portion of clamp arm tissue pad 203204 contacts tissue (not shown) located on the pad 203204. In other words, the end effector 203200 closes proximally first so as to apply full clamp pressure to only the proximal

portion of the grasped tissue while clamp force progressively rolls or expands in the distal direction. As the end effector 203000 reaches the full closure stroke depicted in FIG. 29C, more clamp pressure is gradually distally. In FIG. 29C, the full closure pressure profile or force distribution is achieved in the full closure position of end effector 203000. As discussed above, relatively more clamp pressure can be applied in the proximal portion of the end effecting portion of the ultrasonic blade 203026 to account for the relatively low proximal velocity of the ultrasonic blade 203026, for example.

[0305] FIGS. 30A-30D are sectional views of the end effector 203220 that illustrate a distal start closure stroke configuration and indicate associated part stresses, in accordance with at least one aspect of the present disclosure. In the distal start closure stroke configuration, the end effector 203220 first closes at the distal tip, as illustrated in FIG. 30A and as described above. Thus, the control circuit is configured to control closure of the clamp arm 203224 by pivoting the clamp arm 203224 to create an initial contact point of the ultrasonic blade 203226 and clamp arm 203224 at a distal end of the end effector 203220. In FIG. 30A, the distal tip of clamp arm 203224 contacts ultrasonic blade 203226. In this way, the clamp arm tissue pad 203224 of clamp arm 203224 compresses against the grasped tissue at the distal portion first. Unlike in FIGS. 29A-29C, the applied clamp pressure in FIGS. 30A-30D rolls in the proximal direction. Also, the ultrasonic blade 203226 may be curved, sloped, or otherwise offset to allow for closing at the distal tip first. FIG. 30B depicts the end effector 203220 starting to apply more clamp pressure at the clamp arm tissue pad 203224, moving in the proximal direction. As such, the contours 203228 illustrate the associated part stresses in response to this increased bending of the clamp arm 203224. FIG. 30C shows the continued progression of the applied clamp pressure, in which a majority of the tissue treating portion of the end effector 203220 is in the fully compression position. The tissue treating portion may refer to the portion of the end effector that includes the clamp arm tissue pad 203224. As can be seen in FIGS. 30A-30D, the pad 203224 does not extend to the intersection between the clamp arm 203224 and ultrasonic blade 203226 at the proximal portion of end effector 203220. Based on this configuration, the end effector has a slight proximal gap 203230, which can be beneficial for heat mitigation as described above.

[0306] In FIG. 30D, the end effector 203220 has achieved the full closure stroke, while advantageously maintaining the proximal gap 203230. As the end effector 203220 progressively approaches a full closure position, one or more of the clamp arm 203224 and ultrasonic blade 203226 progressively realizes greater part stresses arising from the increased bending force that is exerted. In accordance, the part stresses gradually increase in correspondence with the transition from FIGS. 30A, 30C, 30C to 30D. Consequently, the greatest occurrence of contours 203228 occurs in FIG. 30D. As illustrated in FIGS. 30A-30D and moving in a proximal direction, incrementally more of the clamp arm tissue pad 203224

becomes active as more of the end effector 203220 closes. The depicted closure sequence culminates in FIG. 30D in which the entire available surface area of pad 203224 is used to compress against grasped tissue and ultrasonic blade 203226 while the portion of the end effector 203220 that is proximal to the proximal extent of the pad 203224 and grasped tissue defines the proximal gap 203230. Although the pad 203224 may terminate at the distal-most extent of the proximal gap 203230, the pad 203224 could also extend into the proximal gap 203230. Even where the pad 203224 extends in this way, the clamp arm 203222 is recessed to assist in defining the proximal gap 203230. In the proximal gap 203230, less electrosurgical energy is delivered, which may advantageously reduce the temperatures and heat residing in the ultrasonic blade 203226 after activating energy delivery by the generator 4002. The control circuit 710 may be configured to execute matching or corresponding deflections of the clamp arm 203224 and ultrasonic blade 203226 such that each of the clamp arm 203224 and ultrasonic blade 203226 deform, deflect, or bend to the same extent in transitioning from the configuration of FIG. 30A to FIG. 30D.

[0307] Moreover, the applied clamp pressure as well as displacement and velocity of ultrasonic blade 203226 can be controlled depending on the progression of the closure stroke. For example, when the end effector 203220 is only closed at the distal tip or approximately only the distal portion (e.g., in FIGS. 30A-30B), the displacement and/or velocity of the ultrasonic blade 203226 can be reduced in order to prevent excessive wear or deterioration of the pad 203224. Thus, ultrasonic oscillation can be reduced when the end effector 203220 is not fully closed. As described above, displacement may be relatively high at the distal tip portion, so reduction in blade displacement may be desirable for the distal start closure configuration of the end effector 203220. Additionally, the control circuit 710 may be configured to control closure of one or more of the clamp arm 203222 and ultrasonic blade 203226 to vary the pressure applied to provide a threshold control pressure based on the cut progression location (e.g., corresponding weld focal point). For example, as the end effector 203220 advances from FIGS. 30A to 30D, a surgical cut or coagulation focal point may shift along the length of the ultrasonic blade 203226, which can be used to adjust applied clamp pressure. The shift may be proximal or distal, depending on the selected closure stroke configuration, for example. When the focal point is at the center portion of the distal half of the end effector 203220, for example, relatively more pressure may be applied at that center portion while relative less pressure might be applied at locations distal to the center portion.

[0308] Additionally or alternatively to adjustments to clamp arm forces based on cut/coagulation focal point, the control circuit 710 may generally apply a relatively lower distal pressure and higher proximal force to address the displacement or velocity profile of the ultrasonic blade 203226. As discussed above, the displacement or velocity of the

ultrasonic blade 203226 is relatively higher at distal portions, so applied forces may be lower at those portions compared to proximal portions. The ultrasonic blade 203226 may be made of a suitable material, such as titanium metal or alloy. More specifically, the titanium alloy could be a grade 5 alpha/beta titanium alloy such as Ti-6Al-4V or it could be some other suitable metal. The clamp arm 203224 could also be made of a suitable material such as stainless steel and more particularly, a precipitation-hardened 17-4 stainless steel. Also, the clamp arm tissue pad 203224 may be electrically conductive based on conductive fillers (e.g., carbon, carbon nanotubes, metallic particles) so that the surgical instrument 7012 can conduct electrical current from the ultrasonic blade 203226 to the pad 203224 via isolated electrical conduits after the end effector 203220 is fully closed. This way, electrosurgical energy such as therapeutic or sub-therapeutic RF can be delivered to the grasped tissue.

[0309] FIGS. 31A-31D are graphs 203240, 203260, 203280, 203300 of clamp force applied between the ultrasonic blade 203226 and clamp arm 203224 as a function of distance from the distal tip of the end effector 203220 corresponding to the sectional views of FIGS. 30A-30D, in accordance with at least one aspect of the present disclosure. The graphs 203240, 203260, 203280, 203300 contain legends 203250, 203270, 203290, 203310, respectively, which has different dot patterns denoting the associated degree of force due to compression between the ultrasonic blade 203226 and clamp arm 203224, for example. Pressure contours 203308 are plotted along the corresponding blade models 203252, 203272, 203292, 203312, which are a generic depiction of the length of ultrasonic blade 203226. The pressure contours 203308 may be indicative of the amount and location of component stresses applied relative to the distance away from the distal tip of the end effector 203220. The dotted line 203254, 203274, 203294, 203314 denotes the proximal end of the tissue effecting portion (e.g., the proximal end of the pad 203224) of the end effector 203220. As can be seen in FIGS. 31A-31D, the pressure contours 203308 start at the distal tip of the end effector 203220 and transition proximally towards the dotted line 203254, 203274, 203294, 203314. In the graphs 203240, 203260, 203280, 203300, the x-axis 203244, 203264, 203284, 203304 denotes the distance from the distal tip of the end effector 203220.

[0310] The y-axis 203246, 203266, 203286, 203306 denotes the applied clamp force resulting from contact between the ultrasonic blade 203226 and clamp arm 203224. The applied force is represented by the applied force line 203242, 203262, 203282, 203302. In FIG. 14A, the applied clamp force only occurs at the distal tip, which corresponds to the distal tip first closure of the distal start closure stroke configuration. The application of the clamp force gradually shifts proximally, as illustrated by the change in applied force line 203242, 203262, 203282, 203302 from FIGS. 31A to 31D. Furthermore, the amplitude of the applied clamp force also gradually increases from FIGS. 31A to 31D. The graphs 203240,

203260, 203280, 203300 may display a similar progression in clamp force as that depicted in FIGS. 28A-28C, except that the two series of graphs progress in opposite directions. Nonetheless, the distributed force or pressure profile depicted in graph 203300 may mirror that of graph 203180. That is, although FIGS. 31A to 31D depict applied pressure transitioning proximally while FIGS. 28A-28C depict pressure transitioning distally, the force profile when the full closure stroke is achieved is the same or similar regardless of the selected closure stroke configuration. The component stresses of the closure stroke according to FIGS. 31A-31D are represented by indicators 203248, 203268, 203288, 203308. Additionally, the position sensor 784 or other sensor 788 could be used to detect the vessel location along the length of the ultrasonic blade 203226 for grasped tissue. This detection might be used to adjust the closure stroke in real-time so as to target the blood vessel for application of maximum force on top of the vessel. This detection could also be used to refrain from applying power into portions of the end effector 203220 that do not contact tissue. This could be useful for heat mitigation.

[0311] FIGS. 32A-32E are sectional views of the end effector 203340 that illustrate a distal start closure stroke configuration and indicate associated part stresses, in accordance with at least one aspect of the present disclosure. As can be seen in FIG. 32A-32E, the ultrasonic blade 203346 is curved and is deformable so that the curvature of ultrasonic blade 203346 flattens or bottoms out in the full closure stroke, as depicted in FIGS. 32D-32E. Accordingly, the axis of ultrasonic blade 203346 is offset. The ultrasonic blade 203346 and clamp arm 203342 pivot about pivot point 203348. The clamp arm 203342 includes clamp arm tissue pad 203344. FIGS. 32A-32E illustrate the progression of distal tip first closure on tissue 203350 for application of electrosurgical energy through pad 203344. In FIG. 32B, the distal tip of curved ultrasonic blade 203346 contacts the distal tip of clamp arm 203342 based on pivoting one or more of ultrasonic blade 203346 and clamp arm 203342 toward each other. The ultrasonic blade 203346 and clamp arm 203342 may move approximately an equal distance towards each other during the duration of the closure stroke. The end effector 203340 may compress against the proximal-most extent of the tissue 203350 at this point. The control circuit 710 may be configured to determine an initial clamp pressure to be applied based on the size of the tissue 203350 initially loaded into end effector 203340.

[0312] As can be seen in FIGS. 32B-32C, the deflection of curved ultrasonic blade 203346 continues and rolls proximally. Simultaneously, more of the tissue 203350 is grasped. The deflection may comprise bottoming out the curved ultrasonic blade 203346 by incrementally reducing the instantaneous curvature of the curved ultrasonic blade 203346. At FIG. 32D, the curved ultrasonic blade 203346 is fully bottomed out such that the end effector 203340 is fully closed (i.e, reached the full closure stroke). A portion of the grasped tissue 203350 is fully compressed against the ultrasonic blade 203346 and clamp arm 203342 in the full

closure position so that electrosurgical energy can be delivered through the pad 203344 for cutting and coagulation. The distal to proximal span of the grasped tissue within the end effector 203340 defines the tissue contact area. This tissue contact area may generate a significant amount of heat. For thermal mitigation or reduction, instead of fully bottoming out, the end effector 203340 maintains a deflection of the ultrasonic blade 203346 that is proximal to the proximal most portion of the tissue contact area. This is shown in FIGS. 32A-32E. Thus, the control circuit 7012 may maintain a gap between the ultrasonic blade 203346 and clamp arm 203342 at a point proximal to a proximal end of the tissue. As compared to the fully closed position depicted in FIG. 32D, the portions of the pad 203344 that are not treating tissue (the portions of pad 203344 proximal to the proximal-most extent of tissue contact area) do not receive as much thermal energy. Consequently, peak temperatures and heat residing in the ultrasonic blade 203346 after application of electrosurgical energy is reduced.

[0313] Also shown in ultrasonic blade 203346 are blade models 203352, 203372, 203392, 203412, which illustrate the progression of clamp force along the length of the end effector 203340. First dotted line 203356 represents the distal tip while second dotted line 203358 represents the proximal end of the end effector 203340. The second dotted line 203358 also may represent the proximal-most extent of the tissue 203350 or where the tissue 203350 stops. In the blade model 203352, no force is applied to the ultrasonic blade 203346. In the blade model 203372, the distal tip of the ultrasonic blade 203346 contacts the corresponding portion of clamp arm 203342, so some force is applied to the distal portion of the ultrasonic blade 203346. Areas of greater applied force may be denoted by darker shading of the pressure contours 203376, 203396, 203416. Accordingly, relatively high force represented by pressure contour 203376 is applied to the distal tip in blade model 203372. In the blade model 203392, the end effector 203340 is more partially closed in the proximal direction, so the pressure contour 203396 spans a greater length of the end effector 203340. The pressure contour 203396 may vary depending on the location of the cut/weld focal point so as to provide a constant threshold pressure on the tissue 203350. In the blade model 203392, the end effector 203340 is fully closed and applied clamp force has completed moving proximally during the closure motion. Consequently, the pressure contour 203396 spans an even greater length and terminates at the second dotted line 203358.

Examples

[0314] Various aspects of the subject matter described herein are set out in the following numbered examples:

[0315] Example 1- A surgical instrument comprises an end effector, an ultrasonic transducer, a control circuit, and the control circuit coupled to the end effector. The end

effector comprises: an ultrasonic blade configured to ultrasonically oscillate against tissue; and a clamp arm configured to pivot relative to the ultrasonic blade. The ultrasonic transducer is acoustically coupled to the ultrasonic blade. The ultrasonic transducer is configured to ultrasonically oscillate the ultrasonic blade in response to a drive signal from a generator. The end effector is configured to receive electrosurgical energy from the generator to treat tissue based on the drive signal. The control circuit is configured to: determine one or more of a resonant frequency measure indicative of a thermally induced change in resonant frequency and an electrical continuity measure; calculate a weld focal point based on one or more of the resonant frequency measure and electrical continuity measure; control closure of the clamp arm to vary a pressure applied by the clamp arm to provide a threshold control pressure to the tissue loaded into the end effector, wherein the pressure is varied based on a corresponding weld focal point; and maintain a gap between the ultrasonic blade and clamp arm at a point proximal to a proximal end of the tissue.

[0316] Example 2- The surgical instrument of Example 1, wherein the control circuit is further configured to determine an initial pressure applied by the clamp arm based on a size of the tissue initially loaded into the end effector.

[0317] Example 3- The surgical instrument of Examples 1 or 2, wherein the control circuit is further configured to vary the pressure applied by the clamp arm based on a shift in the weld focal point along the ultrasonic blade.

[0318] Example 4- The surgical instrument of Example 3, wherein the control circuit is further configured to vary the pressure applied by the clamp arm based on an extent of the tissue loaded into the end effector.

[0319] Example 5- The surgical instrument of Examples 1, 2, 3, or 4, wherein the control circuit is further configured to control closure of the clamp arm by pivoting the clamp arm to create an initial contact point of the ultrasonic blade and clamp arm at a distal end of the end effector.

[0320] Example 6- The surgical instrument of Examples 1, 2, 3, 4, or 5, further comprising the generator configured to deliver electrosurgical energy to the end effector to treat tissue based on generating the drive signal.

[0321] Example 7- The surgical instrument of Examples 1, 2, 3, 4, 5, or 6, further comprising a radio frequency (RF) electrode configured to deliver RF energy to the tissue, wherein the control circuit is further configured to adjust one or more of a power level of the RF energy and a power level of the electrosurgical energy based on tissue impedancel.

[0322] Example 8- A method of using a surgical instrument to provide a threshold control pressure, wherein the surgical instrument comprises: an end effector comprising: a ultrasonic blade configured to ultrasonically oscillate against tissue; and a clamp arm configured to pivot relative to the ultrasonic blade; an ultrasonic transducer acoustically

coupled to the ultrasonic blade, the ultrasonic transducer configured to ultrasonically oscillate the ultrasonic blade in response to the drive signal; and a control circuit coupled to the end effector, wherein the end effector is configured to receive electrosurgical energy from a generator to weld tissue based on a generated drive signal and wherein the method comprises: determining, by the control circuit, one or more of a resonant frequency measure indicative of a thermally induced change in resonant frequency and a electrical continuity measure; calculating, by the control circuit, a weld focal point based on one or more of the resonant frequency measure and electrical continuity measure; controlling, by the control circuit, closure of the clamp arm to vary a pressure applied by the clamp arm to provide the threshold control pressure to the tissue loaded into the end effector, wherein the pressure is varied based on a corresponding weld focal point; and maintaining, by the control circuit, a gap between the ultrasonic blade and clamp arm at a point proximal to a proximal end of the tissue.

[0323] Example 9- The method of Example 8, further comprising determining, by the control circuit, an initial pressure applied by the clamp arm based on a size of the tissue initially loaded into the end effector.

[0324] Example 10- The method of Examples 8 or 9, further comprising varying, by the control circuit, the pressure applied by the clamp arm based on a shift in the weld focal point along the ultrasonic blade.

[0325] Example 11- The method of Example 10, further comprising varying, by the control circuit, the pressure applied by the clamp arm based on an extent of the tissue loaded into the end effector.

[0326] Example 12- The method of Examples 8, 9, 10, or 11 further comprising controlling, by the control circuit, closure of the clamp arm by pivoting the clamp arm to create an initial contact point of the ultrasonic blade and clamp arm at a distal end of the end effector.

[0327] Example 13- The method of Examples 8, 9, 10, 11, or 12, further comprising loading the tissue into the end effector from the distal end to a proximal end of the end effector.

[0328] Example 14- The method of Examples 8, 9, 10, 11, 12, or 13, further comprising adjusting, by the control circuit, one or more of a power level of RF energy and a power level of the electrosurgical energy based on tissue impedance, wherein the surgical instrument further comprises a radio frequency (RF) electrode configured to deliver RF energy to the tissue.

[0329] Example 15- A surgical system comprising: a surgical hub configured to receive a clamp pressure algorithm transmitted from a cloud computing system, wherein the surgical hub is communicatively coupled to the cloud computing system; and a surgical instrument

communicatively coupled to the surgical hub, wherein the surgical instrument comprises:an end effector comprising: an offset ultrasonic blade configured to ultrasonically oscillate against tissue; and an offset clamp arm configured to pivot relative to the ultrasonic blade; and an ultrasonic transducer acoustically coupled to the ultrasonic blade, the ultrasonic transducer configured to ultrasonically oscillate the ultrasonic blade in response to a drive signal from a generator, wherein the end effector is configured to receive electrosurgical energy from the generator to weld tissue based on the drive signal; and a control circuit configured to perform the clamp pressure algorithm to: determine one or more of a resonant frequency measure indicative of a thermally induced change in resonant frequency and a electrical continuity measure; calculate an extent of tissue loaded into the end effector based on one or more of the resonant frequency measure and electrical continuity measure; and vary pressure applied by the clamp arm according to a closure pressure profile comprising a first pressure in a proximal half of the end effector that is greater than a second pressure in a distal half of the end effector and to maintain a gap between the ultrasonic blade and clamp arm at a point proximal to a proximal end of the tissue loaded into the end effector when the end effector is fully closed.

[0330] Example 16- The surgical system of Example 15, wherein the control circuit is further configured to close the end effector at a distal end of the end effector prior to closing non-distal end portions of the end effector.

[0331] Example 17- The surgical system of Examples 15 or 16, further comprising: terminating, by the generator, application of the third power level for a third dwell time; determining, by the control circuit, a fourth tissue impedance point; and applying, by the generator, a fourth power level to reach the fourth tissue impedance point.

[0332] Example 18- The surgical system of Example 17, wherein the first and second deflection are shaped according to the closure pressure profile to provide the first pressure.

[0333] Example 19- The surgical system of Examples 15, 16, 17, or 18, wherein the control circuit is further configured to determine a closure position of the clamp arm.

[0334] Example 20- The method of Example 19, wherein the control circuit is further configured to reduce the ultrasonic oscillation of the ultrasonic blade when the end effector is not in fully closed.

[0335] While several forms have been illustrated and described, it is not the intention of Applicant to restrict or limit the scope of the appended claims to such detail. Numerous modifications, variations, changes, substitutions, combinations, and equivalents to those forms may be implemented and will occur to those skilled in the art without departing from the scope of the present disclosure. Moreover, the structure of each element associated with the described forms can be alternatively described as a means for providing the function performed by the element. Also, where materials are disclosed for certain components, other

materials may be used. It is therefore to be understood that the foregoing description and the appended claims are intended to cover all such modifications, combinations, and variations as falling within the scope of the disclosed forms. The appended claims are intended to cover all such modifications, variations, changes, substitutions, modifications, and equivalents.

[0336] The foregoing detailed description has set forth various forms of the devices and/or processes via the use of block diagrams, flowcharts, and/or examples. Insofar as such block diagrams, flowcharts, and/or examples contain one or more functions and/or operations, it will be understood by those within the art that each function and/or operation within such block diagrams, flowcharts, and/or examples can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. Those skilled in the art will recognize that some aspects of the forms disclosed herein, in whole or in part, can be equivalently implemented in integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more processors (e.g., as one or more programs running on one or more microprocessors), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of skill in the art in light of this disclosure. In addition, those skilled in the art will appreciate that the mechanisms of the subject matter described herein are capable of being distributed as one or more program products in a variety of forms, and that an illustrative form of the subject matter described herein applies regardless of the particular type of signal bearing medium used to actually carry out the distribution.

[0337] Instructions used to program logic to perform various disclosed aspects can be stored within a memory in the system, such as dynamic random access memory (DRAM), cache, flash memory, or other storage. Furthermore, the instructions can be distributed via a network or by way of other computer readable media. Thus a machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer), but is not limited to, floppy diskettes, optical disks, compact disc, read-only memory (CD-ROMs), and magneto-optical disks, read-only memory (ROMs), random access memory (RAM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), magnetic or optical cards, flash memory, or a tangible, machine-readable storage used in the transmission of information over the Internet via electrical, optical, acoustical or other forms of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.). Accordingly, the non-transitory computer-readable medium includes any type of tangible machine-readable

medium suitable for storing or transmitting electronic instructions or information in a form readable by a machine (e.g., a computer).

[0338] As used in any aspect herein, the term "control circuit" may refer to, for example, hardwired circuitry, programmable circuitry (e.g., a computer processor including one or more individual instruction processing cores, processing unit, processor, microcontroller, microcontroller unit, controller, digital signal processor (DSP), programmable logic device (PLD), programmable logic array (PLA), or field programmable gate array (FPGA)), state machine circuitry, firmware that stores instructions executed by programmable circuitry, and any combination thereof. The control circuit may, collectively or individually, be embodied as circuitry that forms part of a larger system, for example, an integrated circuit (IC), an application-specific integrated circuit (ASIC), a system on-chip (SoC), desktop computers, laptop computers, tablet computers, servers, smart phones, etc. Accordingly, as used herein "control circuit" includes, but is not limited to, electrical circuitry having at least one discrete electrical circuit, electrical circuitry having at least one integrated circuit, electrical circuitry having at least one application specific integrated circuit, electrical circuitry forming a general purpose computing device configured by a computer program (e.g., a general purpose computer configured by a computer program which at least partially carries out processes and/or devices described herein, or a microprocessor configured by a computer program which at least partially carries out processes and/or devices described herein), electrical circuitry forming a memory device (e.g., forms of random access memory), and/or electrical circuitry forming a communications device (e.g., a modem, communications switch, or optical-electrical equipment). Those having skill in the art will recognize that the subject matter described herein may be implemented in an analog or digital fashion or some combination thereof.

[0339] As used in any aspect herein, the term "logic" may refer to an app, software, firmware and/or circuitry configured to perform any of the aforementioned operations. Software may be embodied as a software package, code, instructions, instruction sets and/or data recorded on non-transitory computer readable storage medium. Firmware may be embodied as code, instructions or instruction sets and/or data that are hard-coded (e.g., nonvolatile) in memory devices.

[0340] As used in any aspect herein, the terms "component," "system," "module" and the like can refer to a computer-related entity, either hardware, a combination of hardware and software, software, or software in execution.

[0341] As used in any aspect herein, an "algorithm" refers to a self-consistent sequence of steps leading to a desired result, where a "step" refers to a manipulation of physical quantities and/or logic states which may, though need not necessarily, take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and

otherwise manipulated. It is common usage to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like. These and similar terms may be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities and/or states.

[0342] A network may include a packet switched network. The communication devices may be capable of communicating with each other using a selected packet switched network communications protocol. One example communications protocol may include an Ethernet communications protocol which may be capable permitting communication using a Transmission Control Protocol/Internet Protocol (TCP/IP). The Ethernet protocol may comply or be compatible with the Ethernet standard published by the Institute of Electrical and Electronics Engineers (IEEE) titled "IEEE 802.3 Standard", published in December, 2008 and/or later versions of this standard. Alternatively or additionally, the communication devices may be capable of communicating with each other using an X.25 communications protocol. The X.25 communications protocol may comply or be compatible with a standard promulgated by the International Telecommunication Union-Telecommunication Standardization Sector (ITU-T). Alternatively or additionally, the communication devices may be capable of communicating with each other using a frame relay communications protocol. The frame relay communications protocol may comply or be compatible with a standard promulgated by Consultative Committee for International Telegraph and Telephone (CCITT) and/or the American National Standards Institute (ANSI). Alternatively or additionally, the transceivers may be capable of communicating with each other using an Asynchronous Transfer Mode (ATM) communications protocol. The ATM communications protocol may comply or be compatible with an ATM standard published by the ATM Forum titled "ATM-MPLS Network Interworking 2.0" published August 2001, and/or later versions of this standard. Of course, different and/or after-developed connection-oriented network communication protocols are equally contemplated herein.

[0343] Unless specifically stated otherwise as apparent from the foregoing disclosure, it is appreciated that, throughout the foregoing disclosure, discussions using terms such as "processing," "computing," "calculating," "determining," "displaying," or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission or display devices.

[0344] One or more components may be referred to herein as "configured to," "configurable to," "operable/operative to," "adapted/adaptable," "able to," "conformable/conformed to," etc. Those skilled in the art will recognize that "configured to"

can generally encompass active-state components and/or inactive-state components and/or standby-state components, unless context requires otherwise.

[0345] The terms "proximal" and "distal" are used herein with reference to a clinician manipulating the handle portion of the surgical instrument. The term "proximal" refers to the portion closest to the clinician and the term "distal" refers to the portion located away from the clinician. It will be further appreciated that, for convenience and clarity, spatial terms such as "vertical", "horizontal", "up", and "down" may be used herein with respect to the drawings. However, surgical instruments are used in many orientations and positions, and these terms are not intended to be limiting and/or absolute.

[0346] Those skilled in the art will recognize that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to claims containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should typically be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations.

[0347] In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean at least the recited number (e.g., the bare recitation of "two recitations," without other modifiers, typically means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, and C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, or C" would include

but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that typically a disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms unless context dictates otherwise. For example, the phrase "A or B" will be typically understood to include the possibilities of "A" or "B" or "A and B."

[0348] With respect to the appended claims, those skilled in the art will appreciate that recited operations therein may generally be performed in any order. Also, although various operational flow diagrams are presented in a sequence(s), it should be understood that the various operations may be performed in other orders than those which are illustrated, or may be performed concurrently. Examples of such alternate orderings may include overlapping, interleaved, interrupted, reordered, incremental, preparatory, supplemental, simultaneous, reverse, or other variant orderings, unless context dictates otherwise. Furthermore, terms like "responsive to," "related to," or other past-tense adjectives are generally not intended to exclude such variants, unless context dictates otherwise.

[0349] It is worthy to note that any reference to "one aspect," "an aspect," "an exemplification," "one exemplification," and the like means that a particular feature, structure, or characteristic described in connection with the aspect is included in at least one aspect. Thus, appearances of the phrases "in one aspect," "in an aspect," "in an exemplification," and "in one exemplification" in various places throughout the specification are not necessarily all referring to the same aspect. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner in one or more aspects.

[0350] Any patent application, patent, non-patent publication, or other disclosure material referred to in this specification and/or listed in any Application Data Sheet is incorporated by reference herein, to the extent that the incorporated materials is not inconsistent herewith. As such, and to the extent necessary, the disclosure as explicitly set forth herein supersedes any conflicting material incorporated herein by reference. Any material, or portion thereof, that is said to be incorporated by reference herein, but which conflicts with existing definitions, statements, or other disclosure material set forth herein will only be incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material.

[0351] In summary, numerous benefits have been described which result from employing the concepts described herein. The foregoing description of the one or more forms has been presented for purposes of illustration and description. It is not intended to be exhaustive or limiting to the precise form disclosed. Modifications or variations are possible in light of the above teachings. The one or more forms were chosen and described in order to illustrate

principles and practical application to thereby enable one of ordinary skill in the art to utilize the various forms and with various modifications as are suited to the particular use contemplated. It is intended that the claims submitted herewith define the overall scope.

CLAIMS

1. A surgical instrument comprising:

an end effector comprising:

a ultrasonic blade configured to ultrasonically oscillate against tissue; and

a clamp arm configured to pivot relative to the ultrasonic blade;

an ultrasonic transducer acoustically coupled to the ultrasonic blade, the ultrasonic transducer configured to ultrasonically oscillate the ultrasonic blade in response to a drive signal from a generator, wherein the end effector is configured to receive electrosurgical energy from the generator to treat tissue based on the drive signal; and

a control circuit coupled to the end effector, the control circuit configured to:

determine one or more of a resonant frequency measure indicative of a thermally induced change in resonant frequency and an electrical continuity measure;

calculate a weld focal point based on one or more of the resonant frequency measure and electrical continuity measure;

control closure of the clamp arm to vary a pressure applied by the clamp arm to provide a threshold control pressure to the tissue loaded into the end effector, wherein the pressure is varied based on a corresponding weld focal point; and

maintain a gap between the ultrasonic blade and clamp arm at a point proximal to a proximal end of the tissue.

2. The surgical instrument of claim 1, wherein the control circuit is further configured to determine an initial pressure applied by the clamp arm based on a size of the tissue initially loaded into the end effector.

3. The surgical instrument of claim 1, wherein the control circuit is further configured to vary the pressure applied by the clamp arm based on a shift in the weld focal point along the ultrasonic blade.

4. The surgical instrument of claim 3, wherein the control circuit is further configured to vary the pressure applied by the clamp arm based on an extent of the tissue loaded into the end effector.

5. The surgical instrument of claim 1, wherein the control circuit is further configured to control closure of the clamp arm by pivoting the clamp arm to create an initial contact point of the ultrasonic blade and clamp arm at a distal end of the end effector.

6. The surgical instrument of claim 1, further comprising the generator configured to deliver electrosurgical energy to the end effector to treat tissue based on generating the drive signal.

7. The surgical instrument of claim 1, further comprising a radio frequency (RF) electrode configured to deliver RF energy to the tissue, wherein the control circuit is further configured to adjust one or more of a power level of the RF energy and a power level of the electrosurgical energy based on tissue impedance.

8. A method of using a surgical instrument to provide a threshold control pressure, wherein the surgical instrument comprises: an end effector comprising: a ultrasonic blade configured to ultrasonically oscillate against tissue; and a clamp arm configured to pivot relative to the ultrasonic blade; an ultrasonic transducer acoustically coupled to the ultrasonic blade, the ultrasonic transducer configured to ultrasonically oscillate the ultrasonic blade in response to the drive signal; and a control circuit coupled to the end effector, wherein the end effector is configured to receive electrosurgical energy from a generator to weld tissue based on a generated drive signal and wherein the method comprises:

determining, by the control circuit, one or more of a resonant frequency measure indicative of a thermally induced change in resonant frequency and a electrical continuity measure;

calculating, by the control circuit, a weld focal point based on one or more of the resonant frequency measure and electrical continuity measure;

controlling, by the control circuit, closure of the clamp arm to vary a pressure applied by the clamp arm to provide the threshold control pressure to the tissue loaded into the end effector, wherein the pressure is varied based on a corresponding weld focal point; and

maintaining, by the control circuit, a gap between the ultrasonic blade and clamp arm at a point proximal to a proximal end of the tissue.

9. The method of claim 8, further comprising determining, by the control circuit, an initial pressure applied by the clamp arm based on a size of the tissue initially loaded into the end effector.

10. The method of claim 8, further comprising varying, by the control circuit, the pressure applied by the clamp arm based on a shift in the weld focal point along the ultrasonic blade.

11. The method of claim 10, further comprising varying, by the control circuit, the pressure applied by the clamp arm based on an extent of the tissue loaded into the end effector.

12. The method of claim 8, further comprising controlling, by the control circuit, closure of the clamp arm by pivoting the clamp arm to create an initial contact point of the ultrasonic blade and clamp arm at a distal end of the end effector.

13. The method of claim 8, further comprising loading the tissue into the end effector from the distal end to a proximal end of the end effector.

14. The method of claim 8, further comprising adjusting, by the control circuit, one or more of a power level of RF energy and a power level of the electrosurgical energy based on tissue impedance, wherein the surgical instrument further comprises a radio frequency (RF) electrode configured to deliver RF energy to the tissue .

15. A surgical system comprising:

a surgical hub configured to receive a clamp pressure algorithm transmitted from a cloud computing system, wherein the surgical hub is communicatively coupled to the cloud computing system; and

a surgical instrument communicatively coupled to the surgical hub, wherein the surgical instrument comprises:

an end effector comprising:

an offset ultrasonic blade configured to ultrasonically oscillate against tissue; and

an offset clamp arm configured to pivot relative to the ultrasonic blade; and

an ultrasonic transducer acoustically coupled to the ultrasonic blade, the ultrasonic transducer configured to ultrasonically oscillate the ultrasonic blade in response to a drive signal from a generator, wherein the end effector is configured to receive electrosurgical energy from the generator to weld tissue based on the drive signal; and

a control circuit configured to perform the clamp pressure algorithm to:

determine one or more of a resonant frequency measure indicative of a thermally induced change in resonant frequency and a electrical continuity measure;

calculate an extent of tissue loaded into the end effector based on one or more of the resonant frequency measure and electrical continuity measure; and

vary pressure applied by the clamp arm according to a closure pressure profile comprising a first pressure in a proximal half of the end effector that is greater than a second pressure in a distal half of the end effector and to maintain a gap between the ultrasonic blade and clamp arm at a point proximal to a proximal end of the tissue loaded into the end effector when the end effector is fully closed.

16. The surgical system of claim 15, wherein the control circuit is further configured to close the end effector at a distal end of the end effector prior to closing non-distal end portions of the end effector.

17. The surgical system of claim 15, wherein a first deflection of the offset ultrasonic blade corresponds to a second deflection of the offset clamp arm.

18. The surgical system of claim 17, wherein the first and second deflection are shaped according to the closure pressure profile to provide the first pressure.

19. The surgical system of claim 15, wherein the control circuit is further configured to determine a closure position of the clamp arm.

20. The surgical system of claim 19, wherein the control circuit is further configured to reduce the ultrasonic oscillation of the ultrasonic blade when the end effector is not in fully closed.

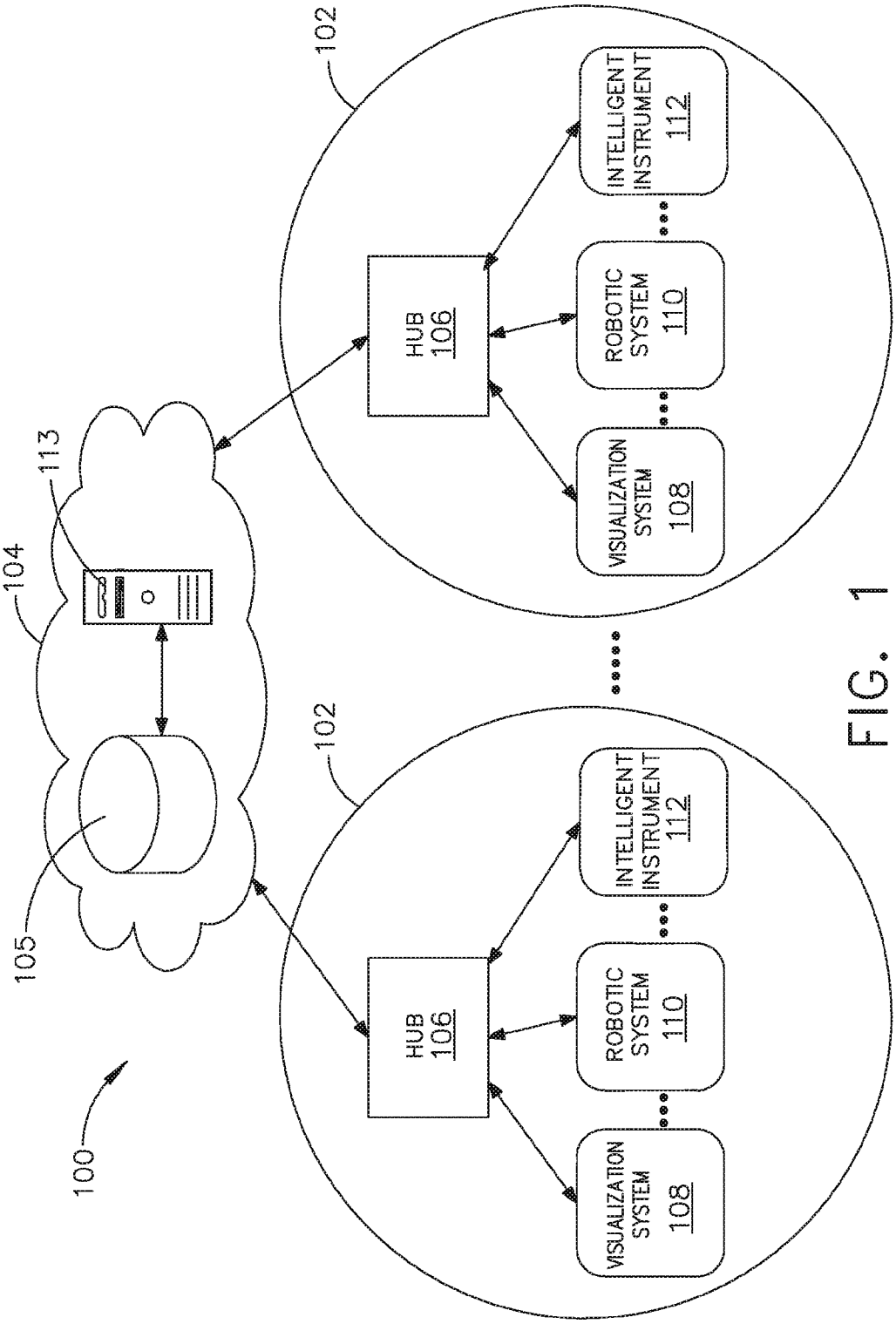

100
105
104
113
102
HUB 106
VISUALIZATION SYSTEM 108
ROBOTIC SYSTEM 110
INTELLIGENT INSTRUMENT 112
102
HUB 106
VISUALIZATION SYSTEM 108
ROBOTIC SYSTEM 110
INTELLIGENT INSTRUMENT 112

FIG. 1

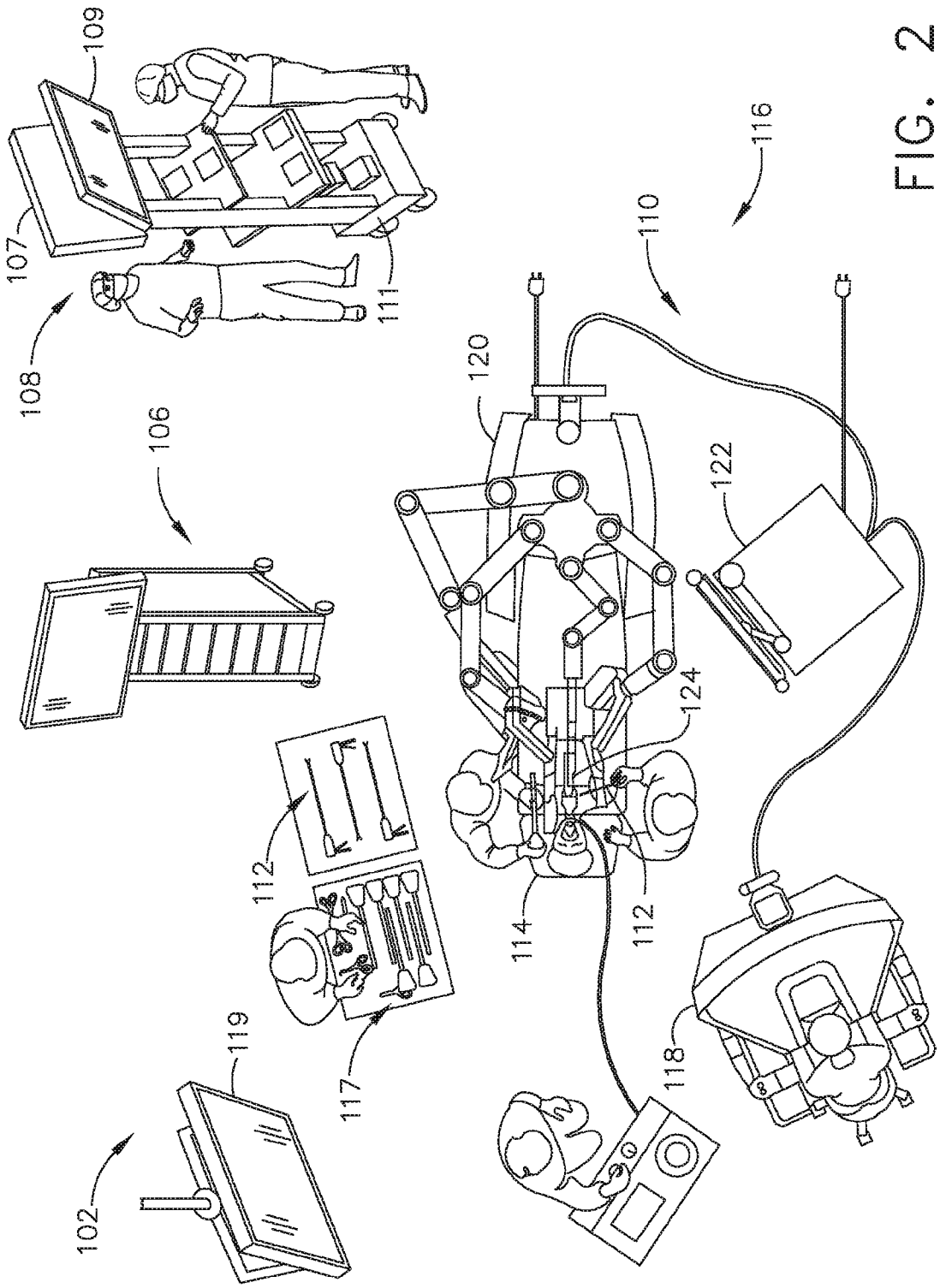

109
107
108
111
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116
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120
122
124
112
114
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117
118
102

FIG. 2

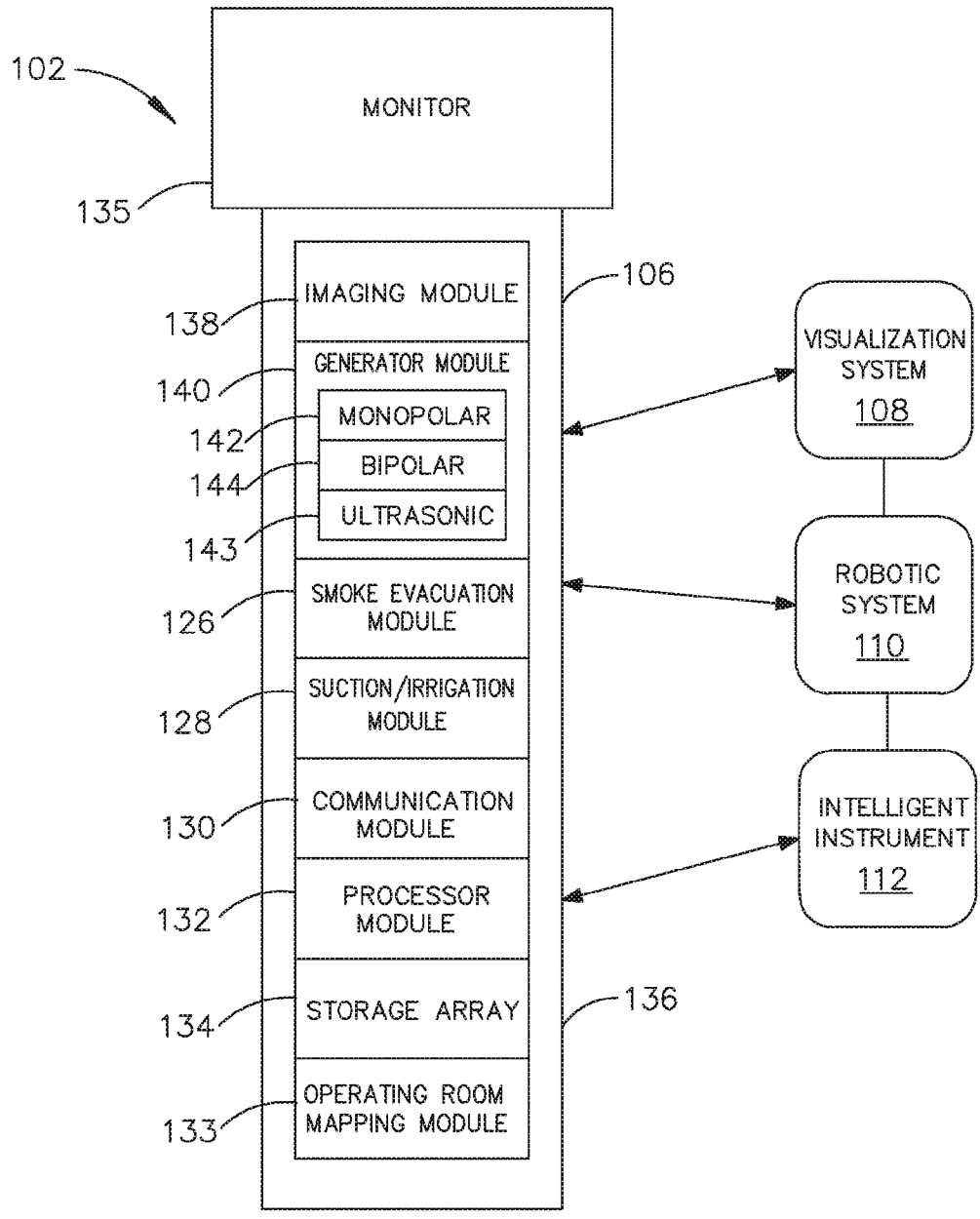

102
MONITOR
135
IMAGING MODULE
138
106
GENERATOR MODULE
140
MONOPOLAR
142
BIPOLAR
144
ULTRASONIC
143
SMOKE EVACUATION MODULE
126
SUCTION/IRRIGATION MODULE
128
COMMUNICATION MODULE
130
PROCESSOR MODULE
132
STORAGE ARRAY
134
136
OPERATING ROOM MAPPING MODULE
133
VISUALIZATION SYSTEM
108
ROBOTIC SYSTEM
110
INTELLIGENT INSTRUMENT
112

FIG. 3

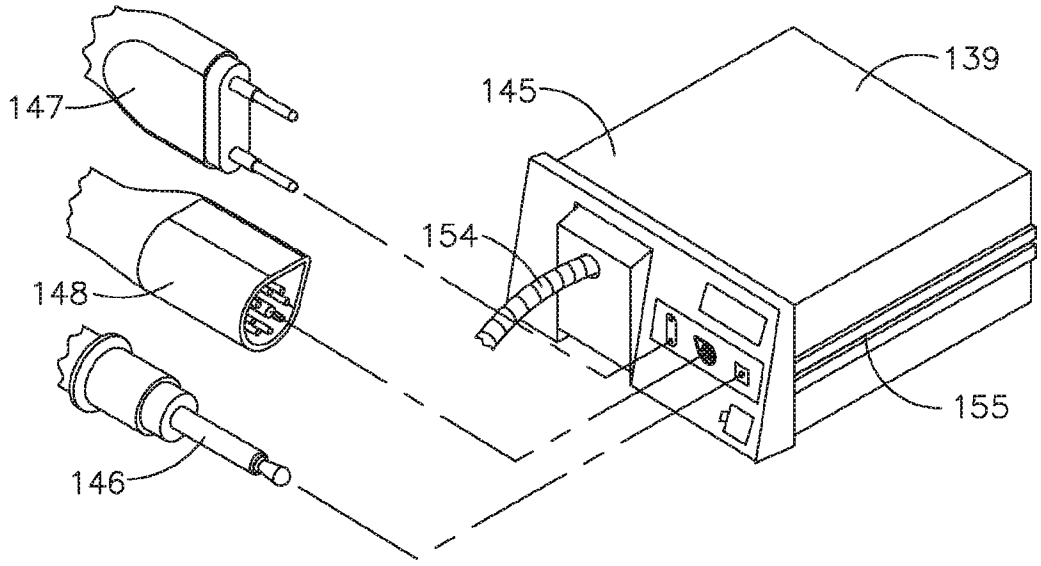

147
148
146
145
154
139
155

FIG. 5

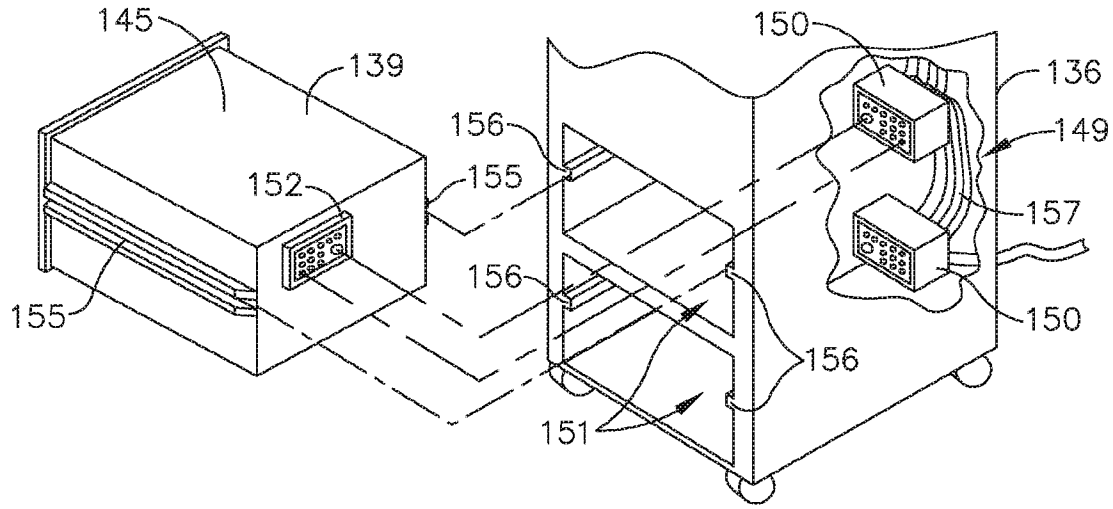

145
139
152
155
156
156
151
150
136
149
157
150

FIG. 4

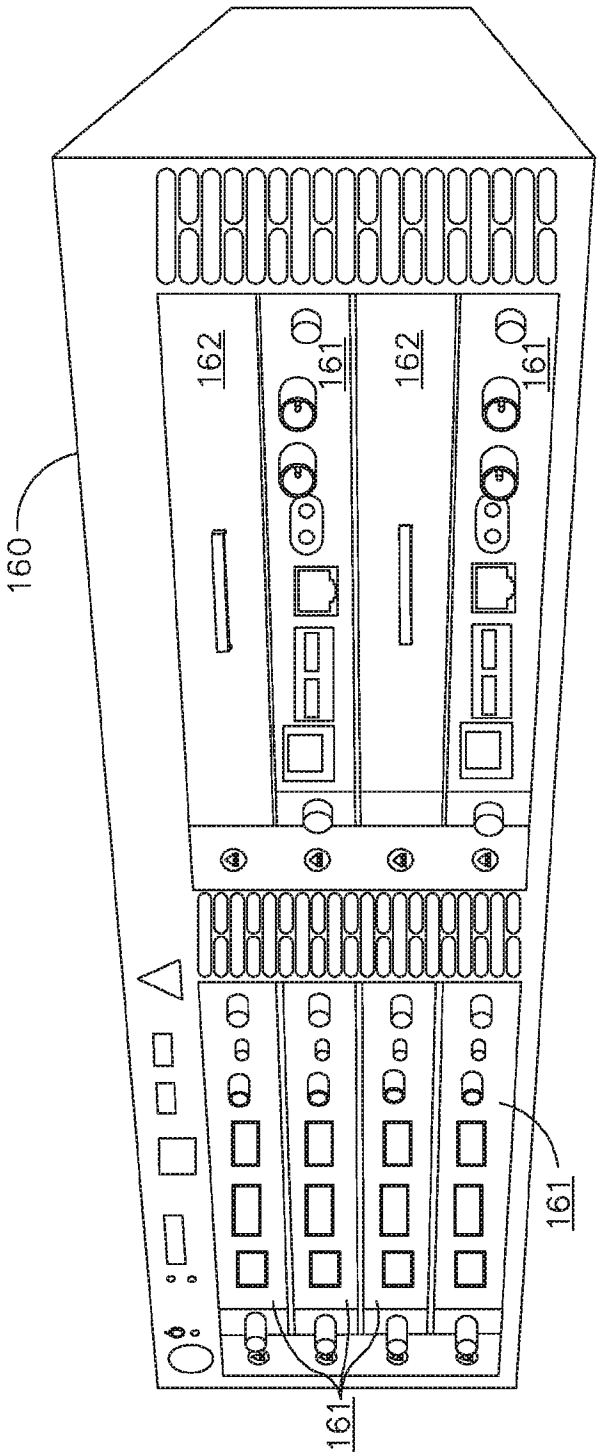


FIG. 6

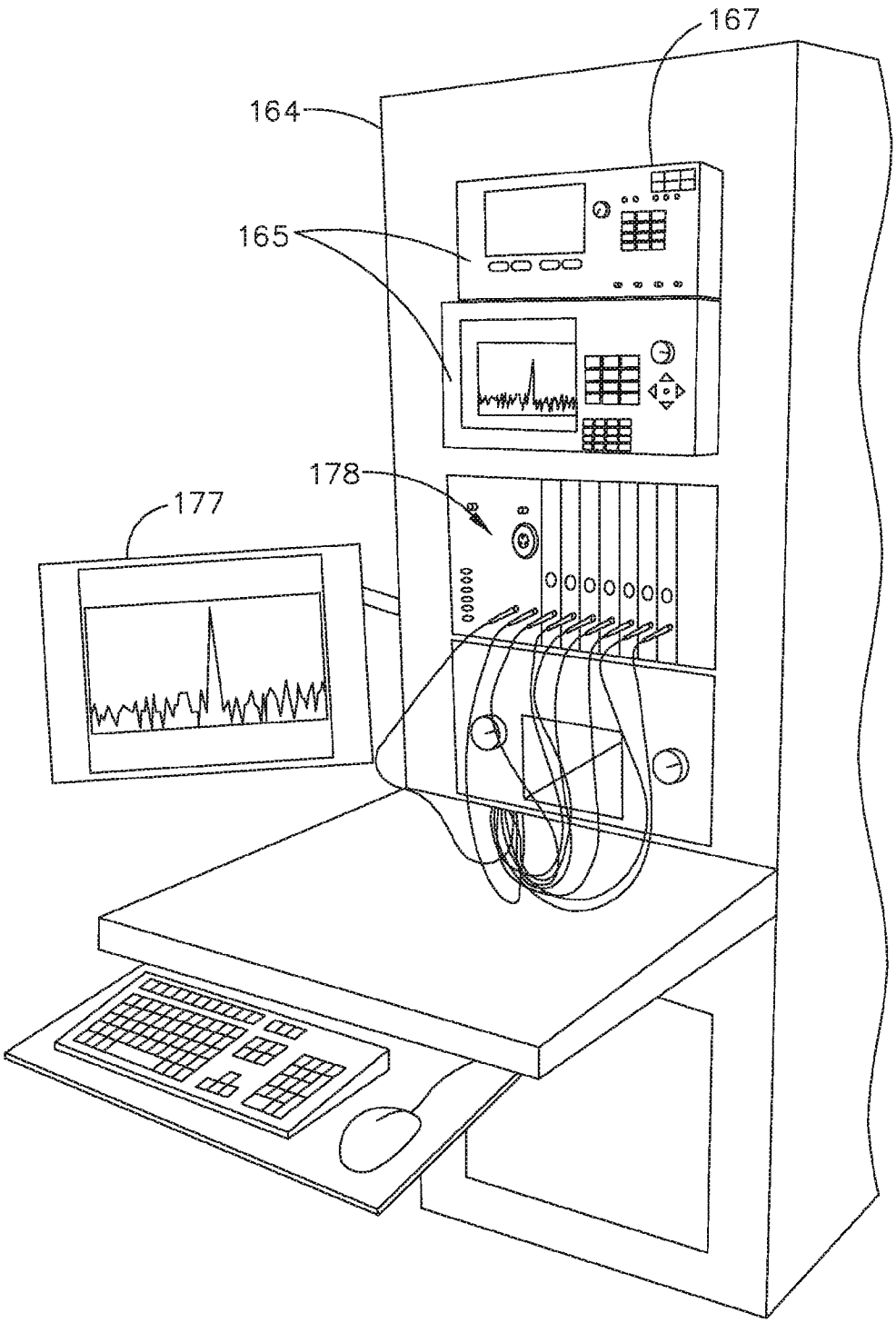


FIG. 7

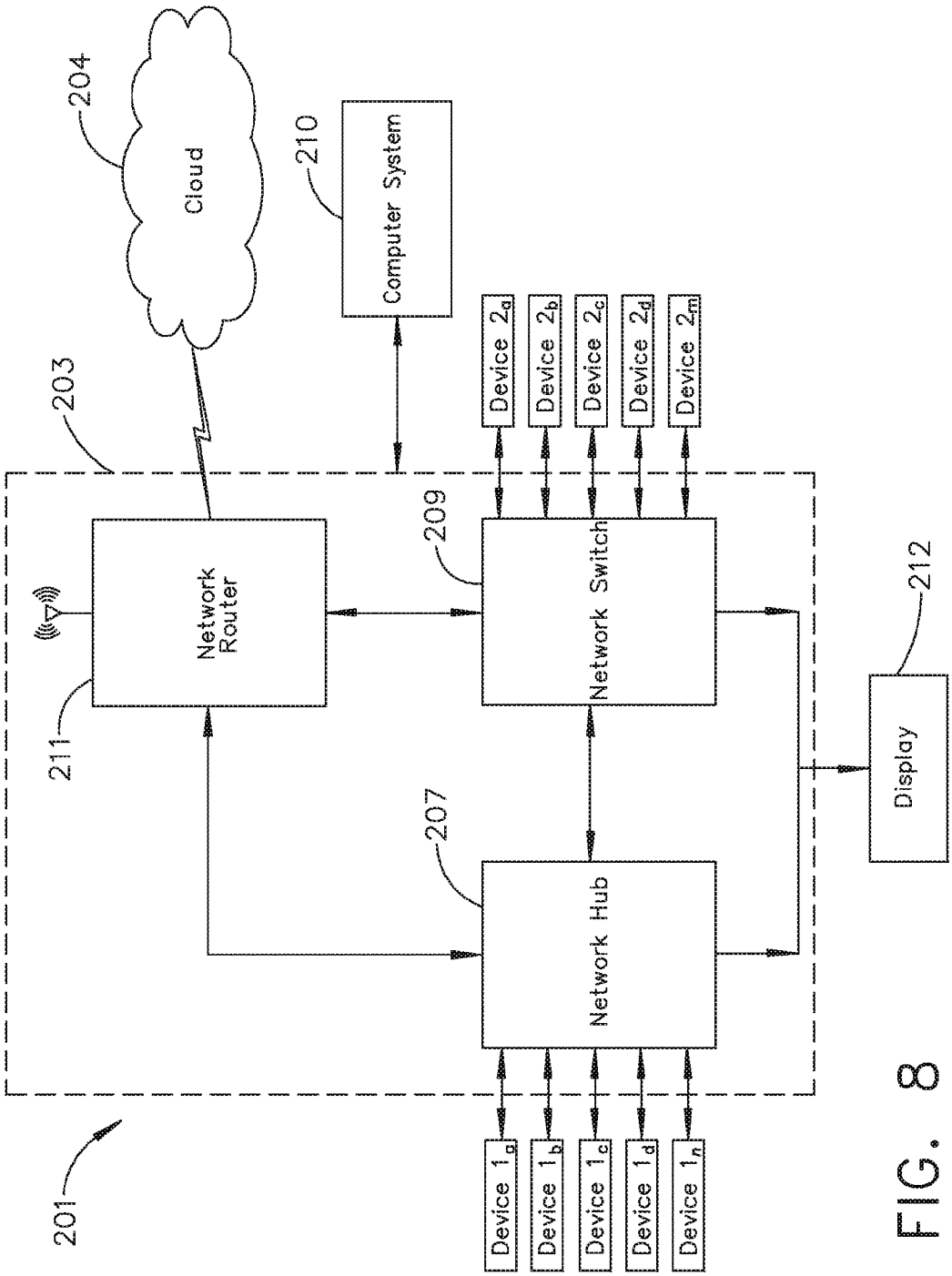

204
Cloud
210
Computer System
Device 2a
Device 2b
Device 2c
Device 2d
Device 2m
203
209
Network Router
Network Switch
212
211
Display
207
Network Hub
201
Device 1a
Device 1b
Device 1c
Device 1d
Device 1n

FIG. 8

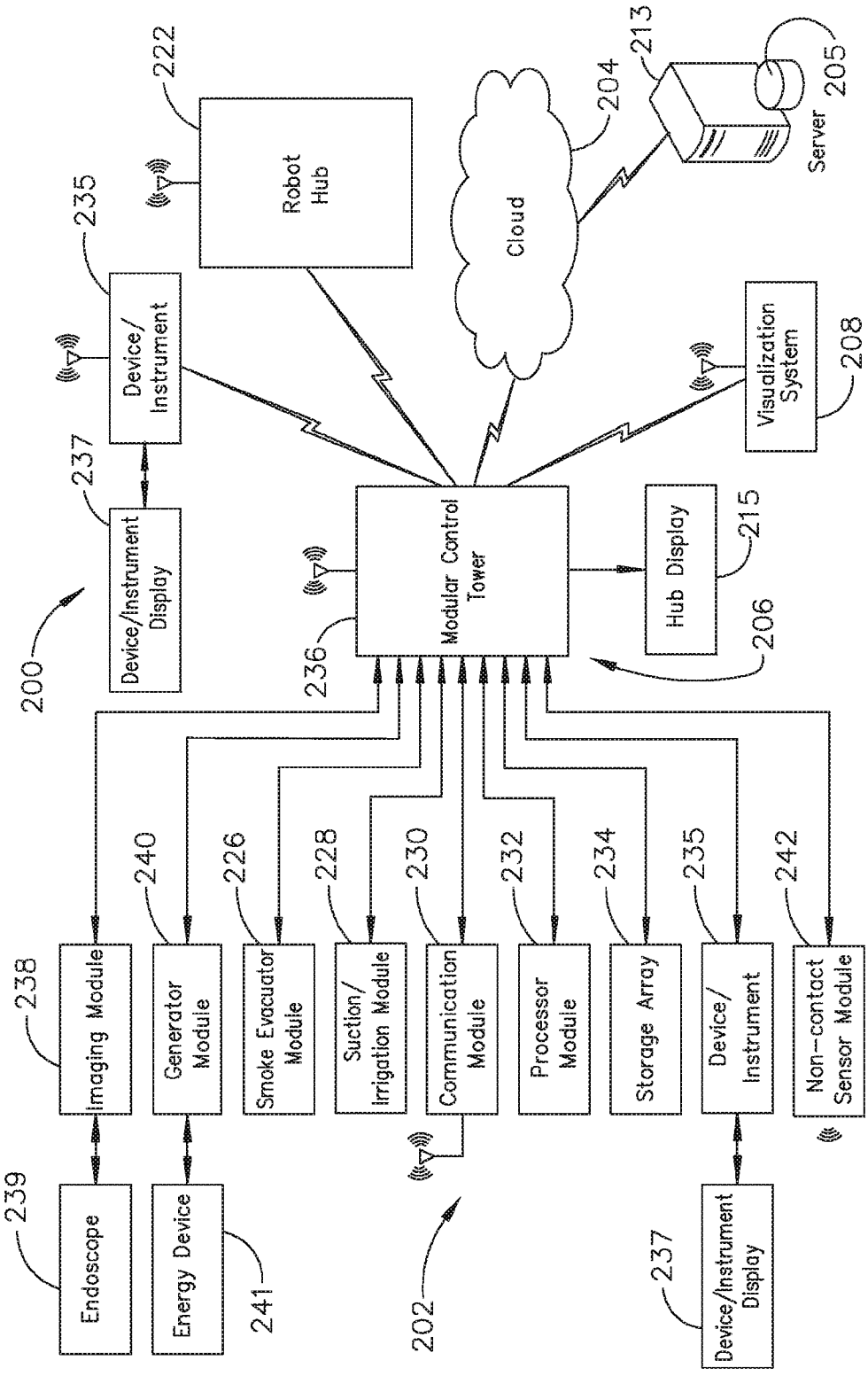

Robot Hub
222
Cloud
204
Server
205
213
Device/ Instrument
235
Visualization System
208
Device/Instrument Display
237
Modular Control Tower
236
Hub Display
215
206
200
Imaging Module
238
Generator Module
240
Smoke Evacuator Module
226
Suction/ Irrigation Module
228
Communication Module
230
Processor Module
232
Storage Array
234
Device/ Instrument
235
Non-contact Sensor Module
242
Endoscope
239
Energy Device
241
202
Device/Instrument Display
237

FIG. 9

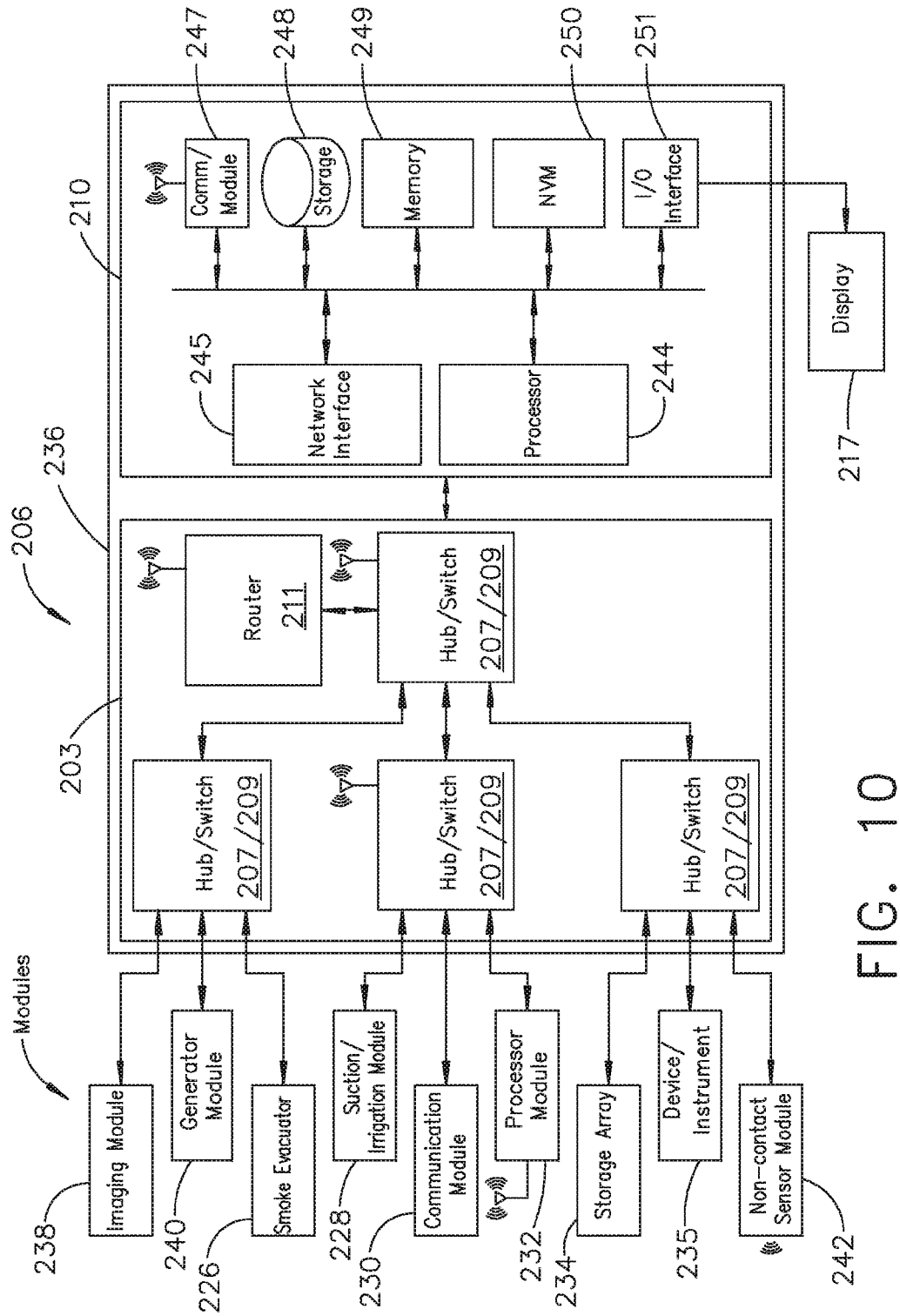

Modules
Imaging Module
Generator Module
Smoke Evacuator
Suction/ Irrigation Module
Communication Module
Processor Module
Storage Array
Device/ Instrument
Non-contact Sensor Module
238
240
226
228
230
232
234
235
242
203
206
236
210
Hub/Switch 207/209
Hub/Switch 207/209
Hub/Switch 207/209
Router 211
Comm/ Module
Storage
Memory
NVM
I/O Interface
247
248
249
250
251
Network Interface
Processor
245
244
Display
217

FIG. 10

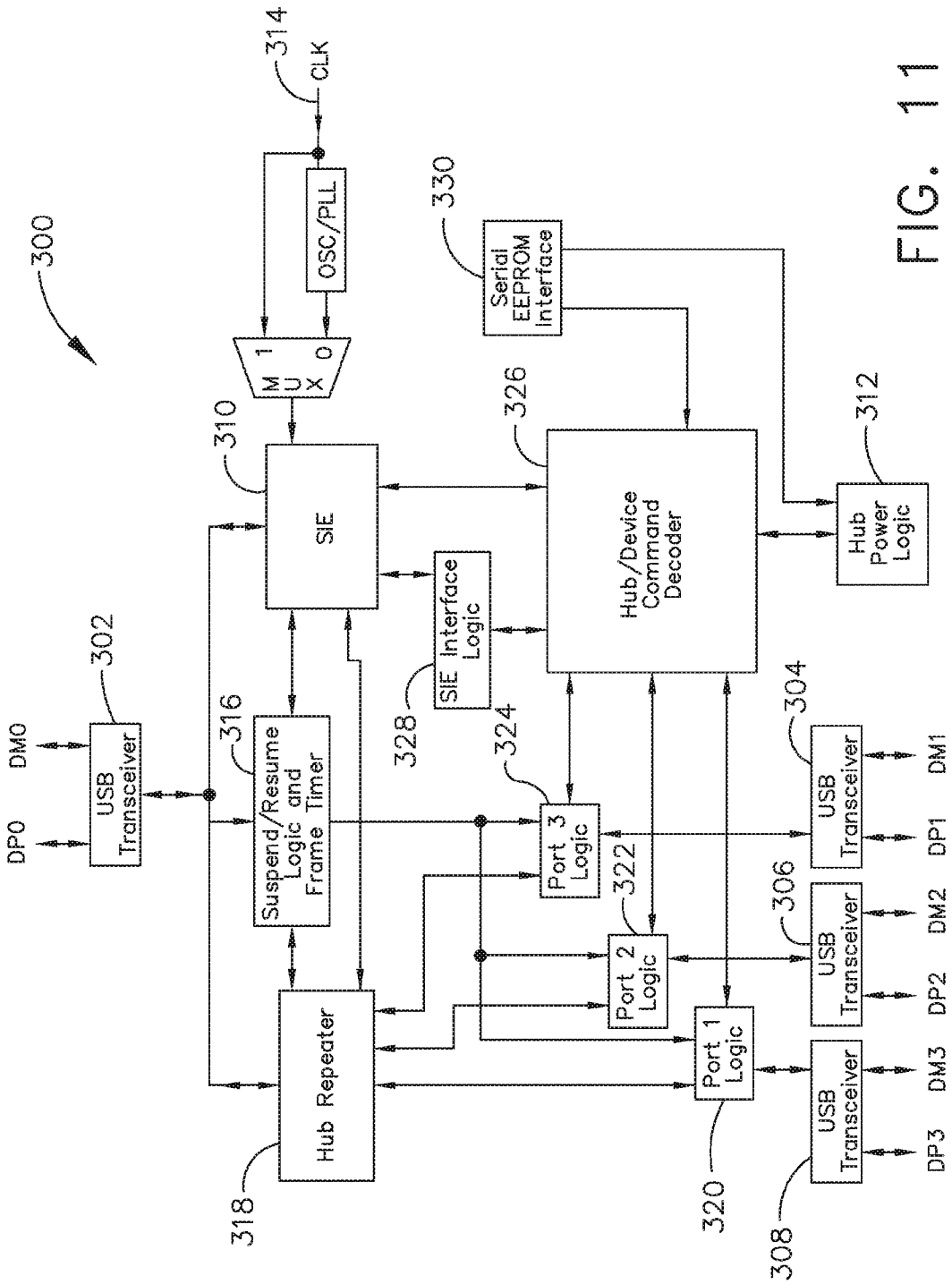

300
314
CLK
OSC/PLL
330
Serial EEPROM Interface
M U X 1 0
310
SIE
326
Hub/Device Command Decoder
312
Hub Power Logic
302
USB Transceiver
DP0
DM0
316
Suspend/Resume Logic and Frame Timer
328
SIE Interface Logic
324
Port 3 Logic
304
USB Transceiver
DP1
DM1
322
Port 2 Logic
306
USB Transceiver
DP2
DM2
Port 1 Logic
USB Transceiver
DP3
DM3
318
Hub Repeater
320
308

FIG. 11

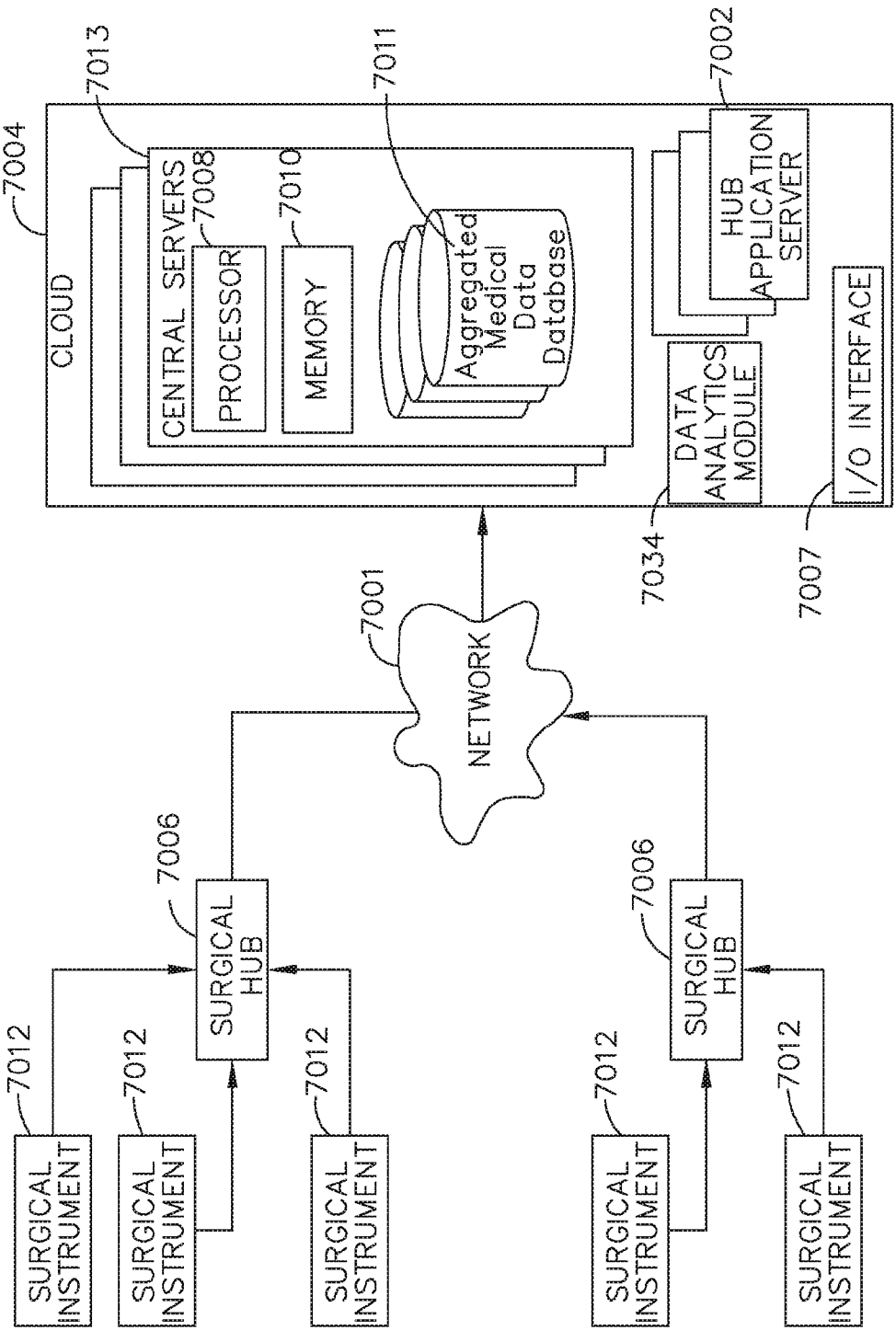

7004
CLOUD
7013
CENTRAL SERVERS
7008
PROCESSOR
7010
MEMORY
7011
Aggregated Medical Data Database
7002
HUB APPLICATION SERVER
DATA ANALYTICS MODULE
7034
I/O INTERFACE
7007
7001
NETWORK
7006
SURGICAL HUB
7006
SURGICAL HUB
7012
SURGICAL INSTRUMENT
7012
SURGICAL INSTRUMENT
7012
SURGICAL INSTRUMENT
7012
SURGICAL INSTRUMENT
7012
SURGICAL INSTRUMENT

FIG. 12

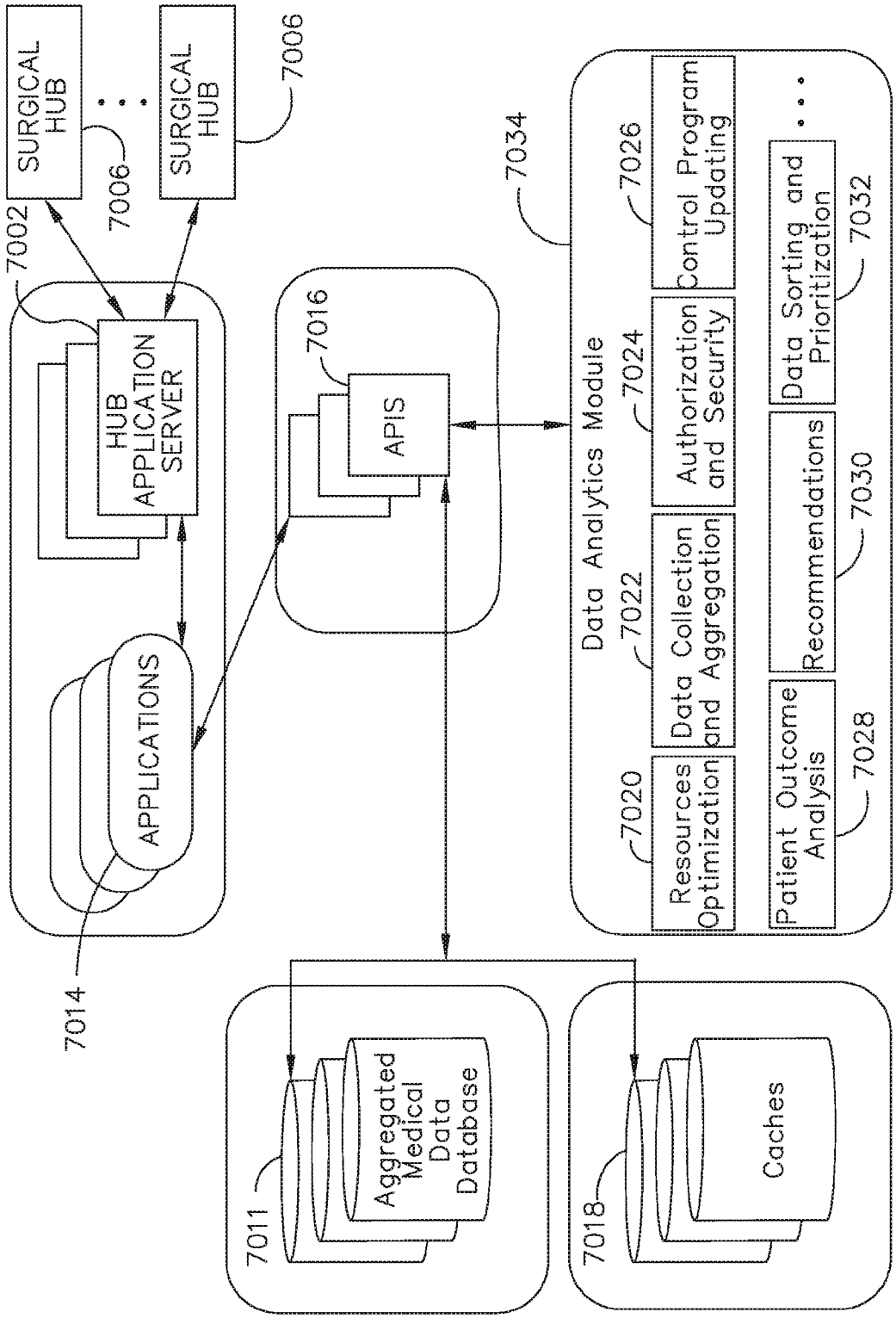

SURGICAL HUB
SURGICAL HUB
7006
7002
HUB APPLICATION SERVER
APPLICATIONS
7014
7016
APIS
7034
Data Analytics Module
7020
Resources Optimization
7022
Data Collection and Aggregation
7024
Authorization and Security
7026
Control Program Updating
7028
Patient Outcome Analysis
7030
Recommendations
7032
Data Sorting and Prioritization
7011
Aggregated Medical Data Database
7018
Caches

FIG. 13

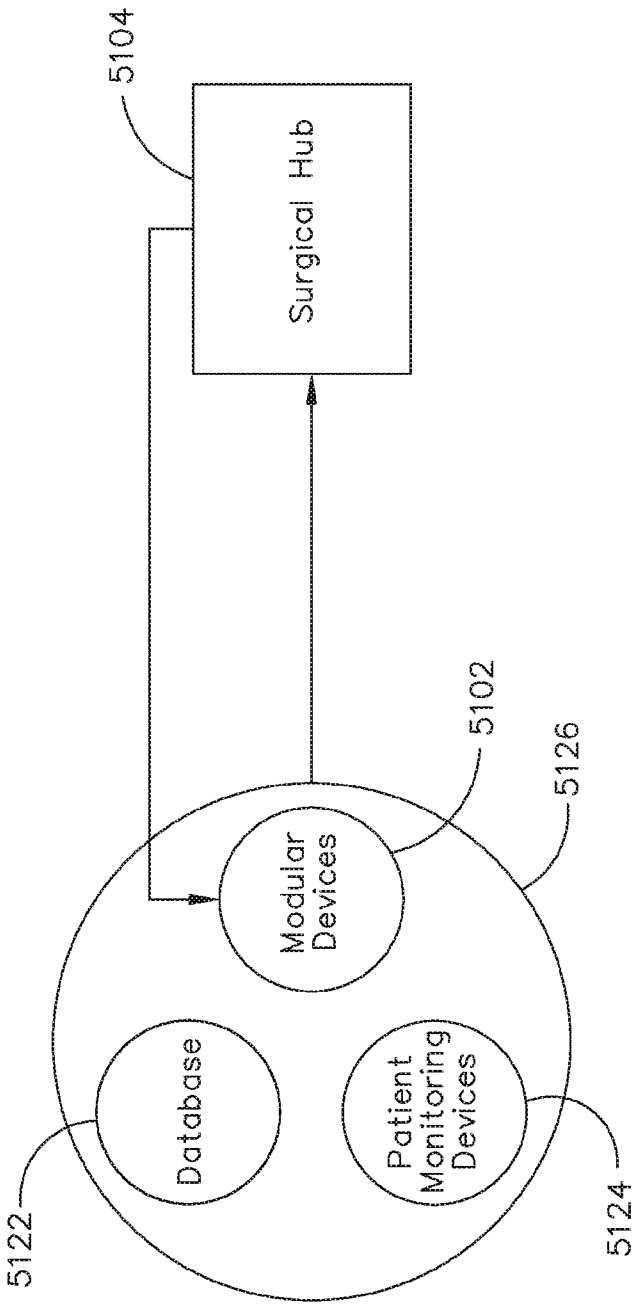

5100
5104
Surgical Hub
5102
5126
Modular Devices
Database
Patient Monitoring Devices
5122
5124

FIG. 14

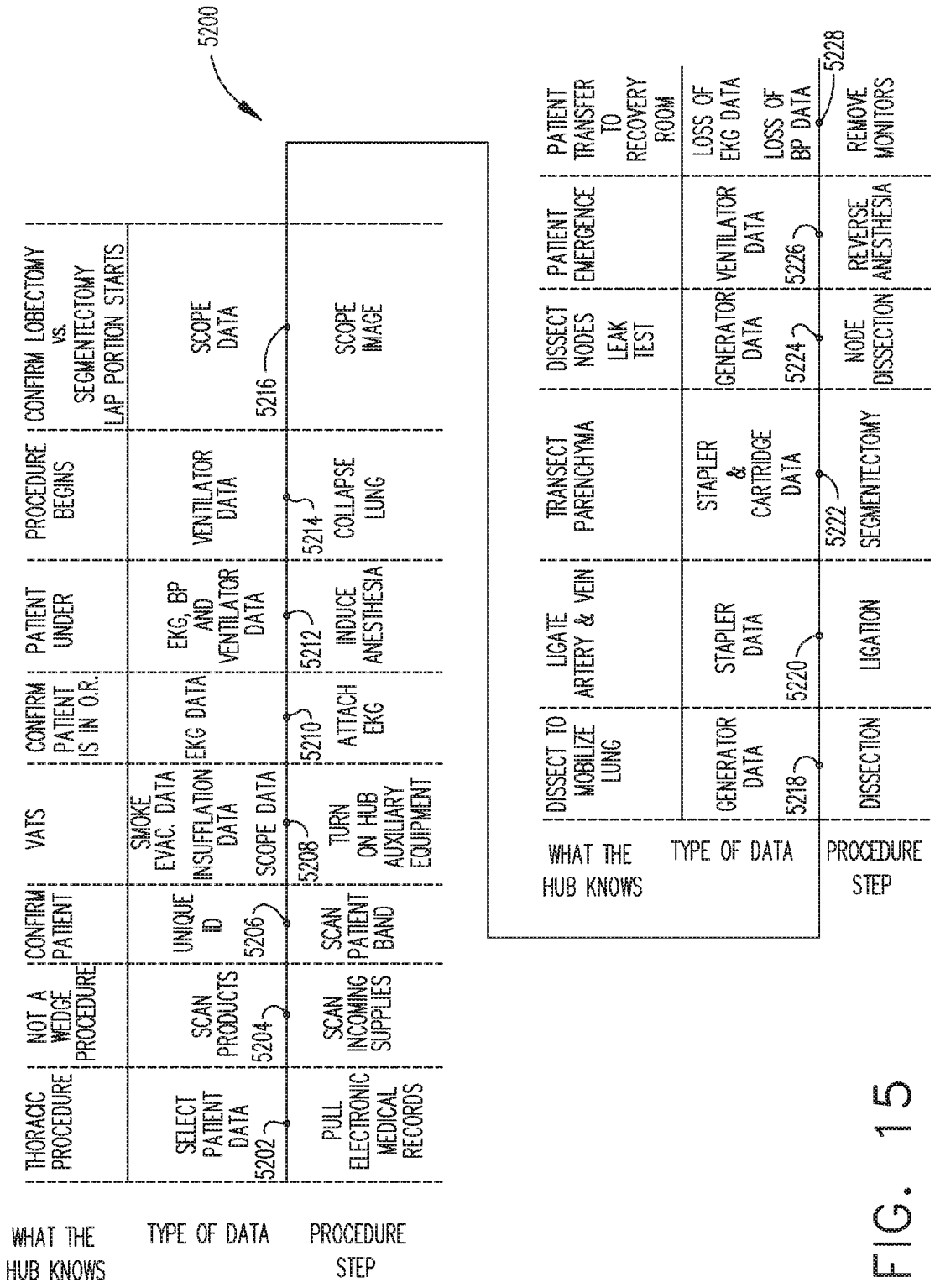

5200
WHAT THE HUB KNOWS
TYPE OF DATA
PROCEDURE STEP
THORACIC PROCEDURE
NOT A WEDGE PROCEDURE
CONFIRM PATIENT
VATS
CONFIRM PATIENT IS IN O.R.
PATIENT UNDER
PROCEDURE BEGINS
CONFIRM LOBECTOMY vs. SEGMENTECTOMY
SELECT PATIENT DATA
5202
SCAN PRODUCTS
5204
UNIQUE ID
5206
SMOKE EVAC. DATA
INSUFFLATION DATA
SCOPE DATA
5208
EKG DATA
EKG, BP AND VENTILATOR DATA
VENTILATOR DATA
SCOPE DATA
5216
PULL ELECTRONIC MEDICAL RECORDS
SCAN INCOMING SUPPLIES
SCAN PATIENT BAND
TURN ON HUB AUXILIARY EQUIPMENT
5210
ATTACH EKG
5212
INDUCE ANESTHESIA
5214
COLLAPSE LUNG
SCOPE IMAGE
DISSECT TO MOBILIZE LUNG
LIGATE ARTERY & VEIN
TRANSECT PARENCHYMA
DISSECT NODES
LEAK TEST
PATIENT EMERGENCE
PATIENT TRANSFER TO RECOVERY ROOM
GENERATOR DATA
5218
STAPLER DATA
5220
STAPLER & CARTRIDGE DATA
5222
GENERATOR DATA
5224
VENTILATOR DATA
5226
LOSS OF EKG DATA
LOSS OF BP DATA
5228
DISSECTION
LIGATION
SEGMENTECTOMY
NODE DISSECTION
REVERSE ANESTHESIA
REMOVE MONITORS

FIG. 15

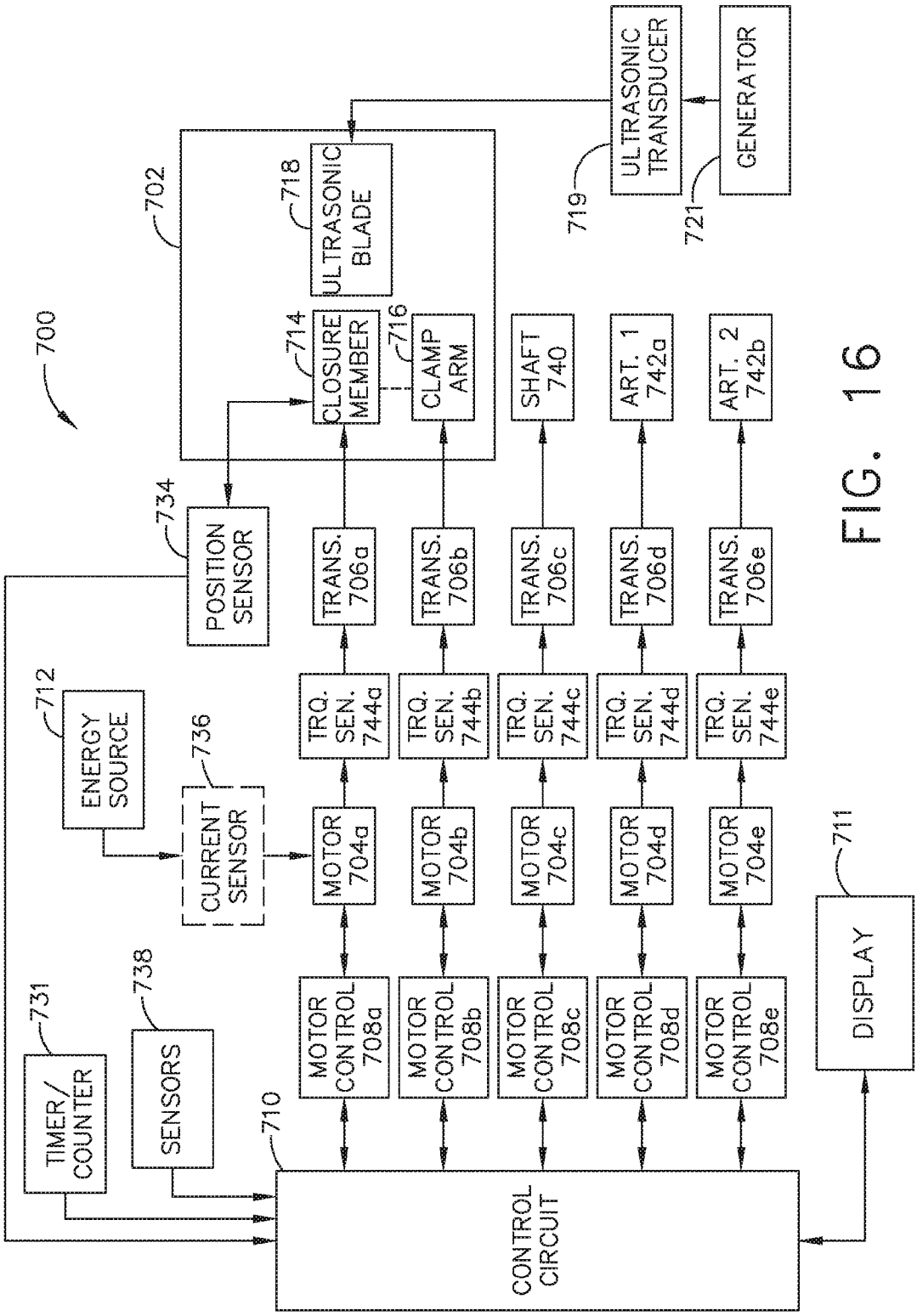

700
702
718
ULTRASONIC BLADE
719
ULTRASONIC TRANSDUCER
721
GENERATOR
714
CLOSURE MEMBER
716
CLAMP ARM
734
POSITION SENSOR
712
ENERGY SOURCE
736
CURRENT SENSOR
738
SENSORS
731
TIMER/ COUNTER
710
CONTROL CIRCUIT
711
DISPLAY
TRANS. 706a
TRANS. 706b
TRANS. 706c
TRANS. 706d
TRANS. 706e
SHAFT 740
ART. 1 742a
ART. 2 742b
TRQ. SEN. 744a
TRQ. SEN. 744b
TRQ. SEN. 744c
TRQ. SEN. 744d
TRQ. SEN. 744e
MOTOR 704a
MOTOR 704b
MOTOR 704c
MOTOR 704d
MOTOR 704e
MOTOR CONTROL 708a
MOTOR CONTROL 708b
MOTOR CONTROL 708c
MOTOR CONTROL 708d
MOTOR CONTROL 708e

FIG. 16

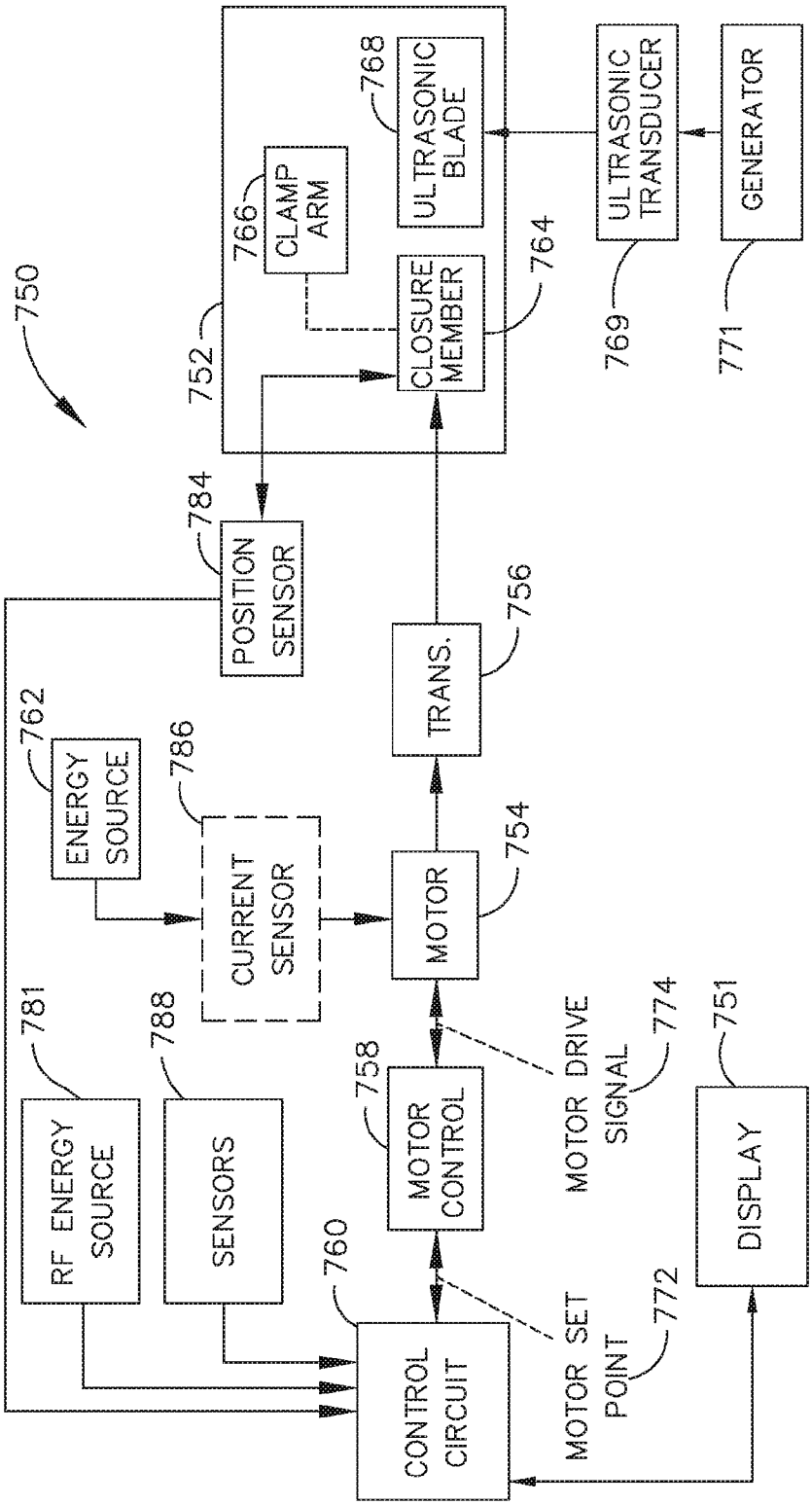

750
752
766
CLAMP ARM
768
ULTRASONIC BLADE
764
CLOSURE MEMBER
ULTRASONIC TRANSDUCER
769
GENERATOR
771
784
POSITION SENSOR
762
ENERGY SOURCE
786
CURRENT SENSOR
TRANS.
756
MOTOR
754
781
RF ENERGY SOURCE
788
SENSORS
758
MOTOR CONTROL
MOTOR DRIVE SIGNAL
774
751
DISPLAY
760
CONTROL CIRCUIT
MOTOR SET POINT
772

FIG. 17

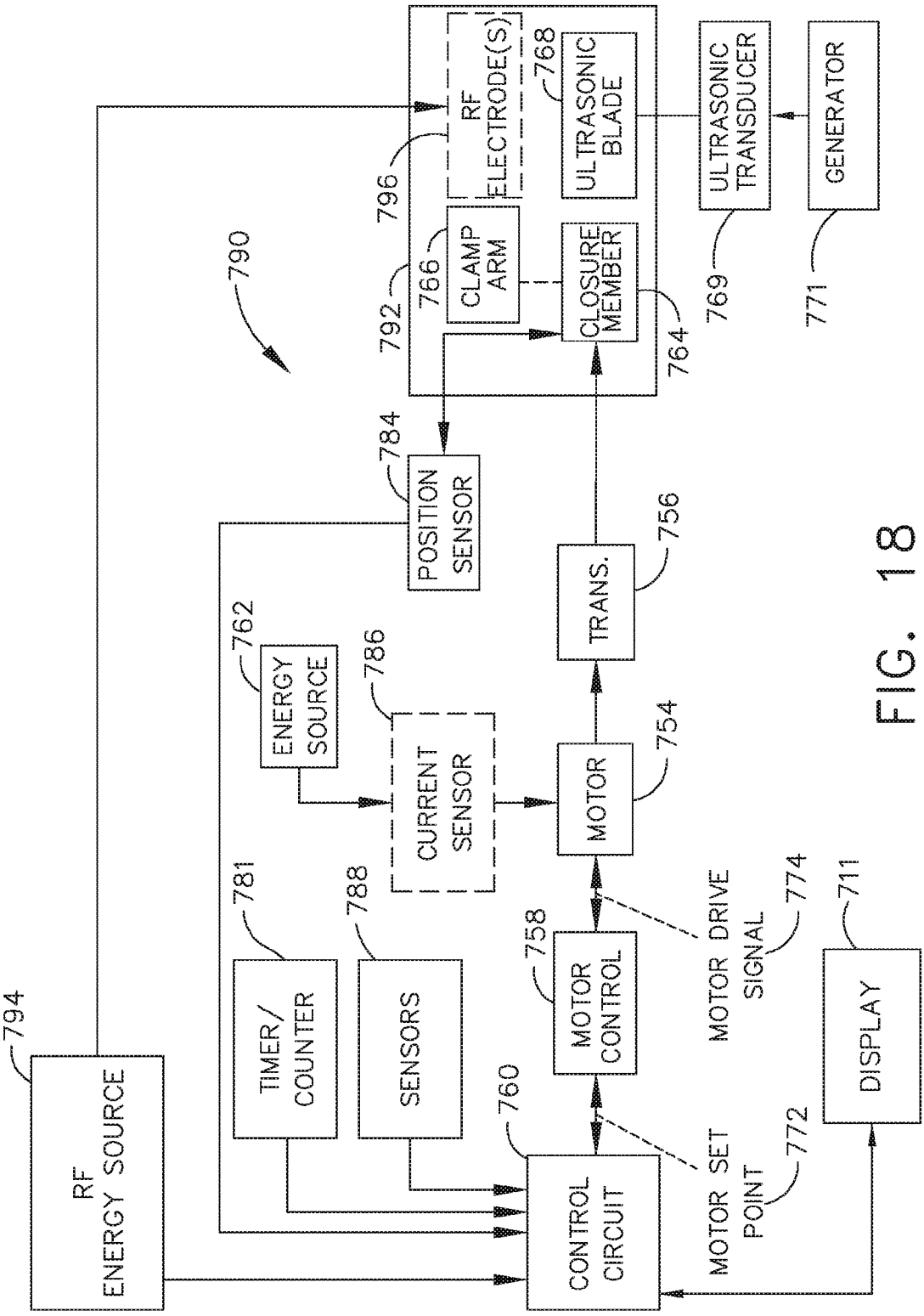

790
794
RF ENERGY SOURCE
760
CONTROL CIRCUIT
781
TIMER/ COUNTER
788
SENSORS
762
ENERGY SOURCE
786
CURRENT SENSOR
784
POSITION SENSOR
758
MOTOR CONTROL
754
MOTOR
756
TRANS.
796
792
766
CLAMP ARM
764
CLOSURE MEMBER
768
RF ELECTRODE(S)
ULTRASONIC BLADE
769
ULTRASONIC TRANSDUCER
771
GENERATOR
774
MOTOR DRIVE SIGNAL
772
MOTOR SET POINT
711
DISPLAY

FIG. 18

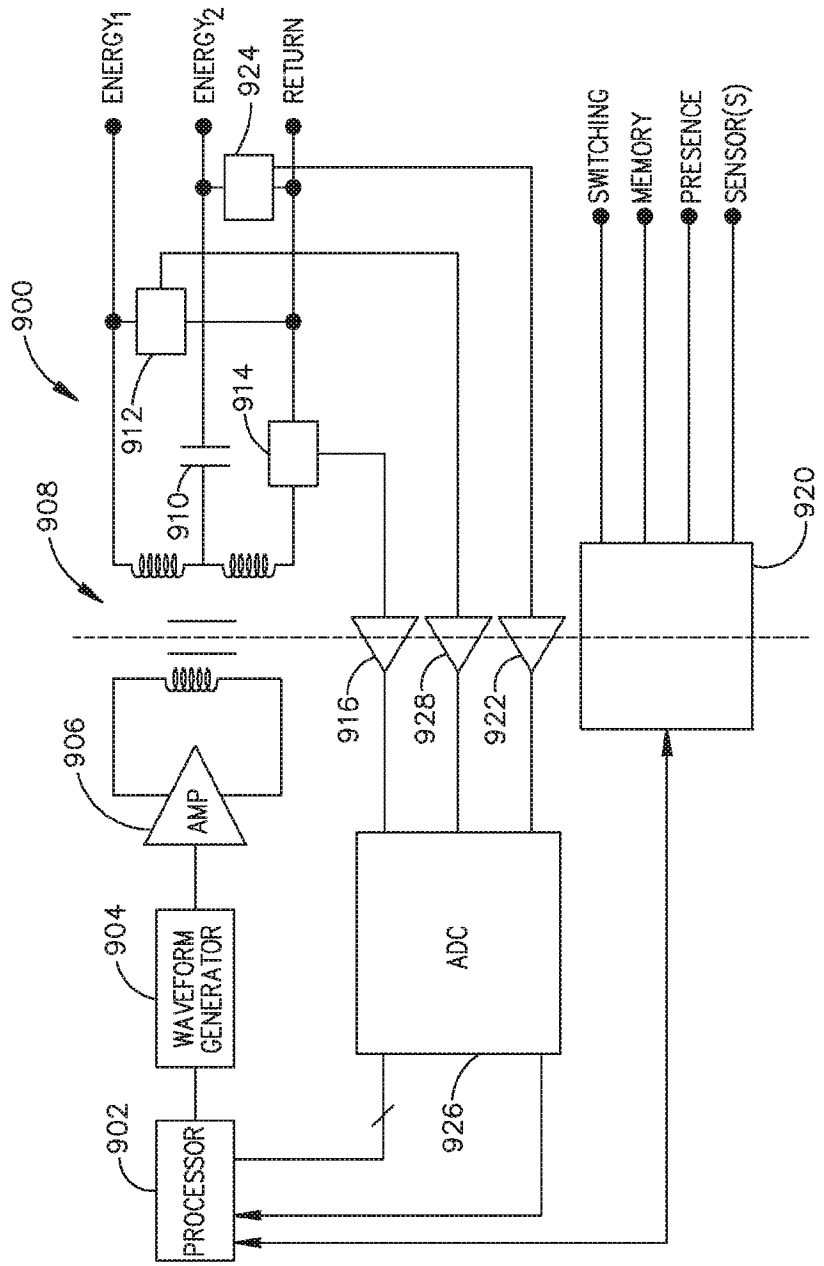

ENERGY1
ENERGY2
924
RETURN
SWITCHING
MEMORY
PRESENCE
SENSOR(S)
900
912
914
910
908
920
916
928
922
906
AMP
904
WAVEFORM GENERATOR
ADC
902
PROCESSOR
926

FIG. 19

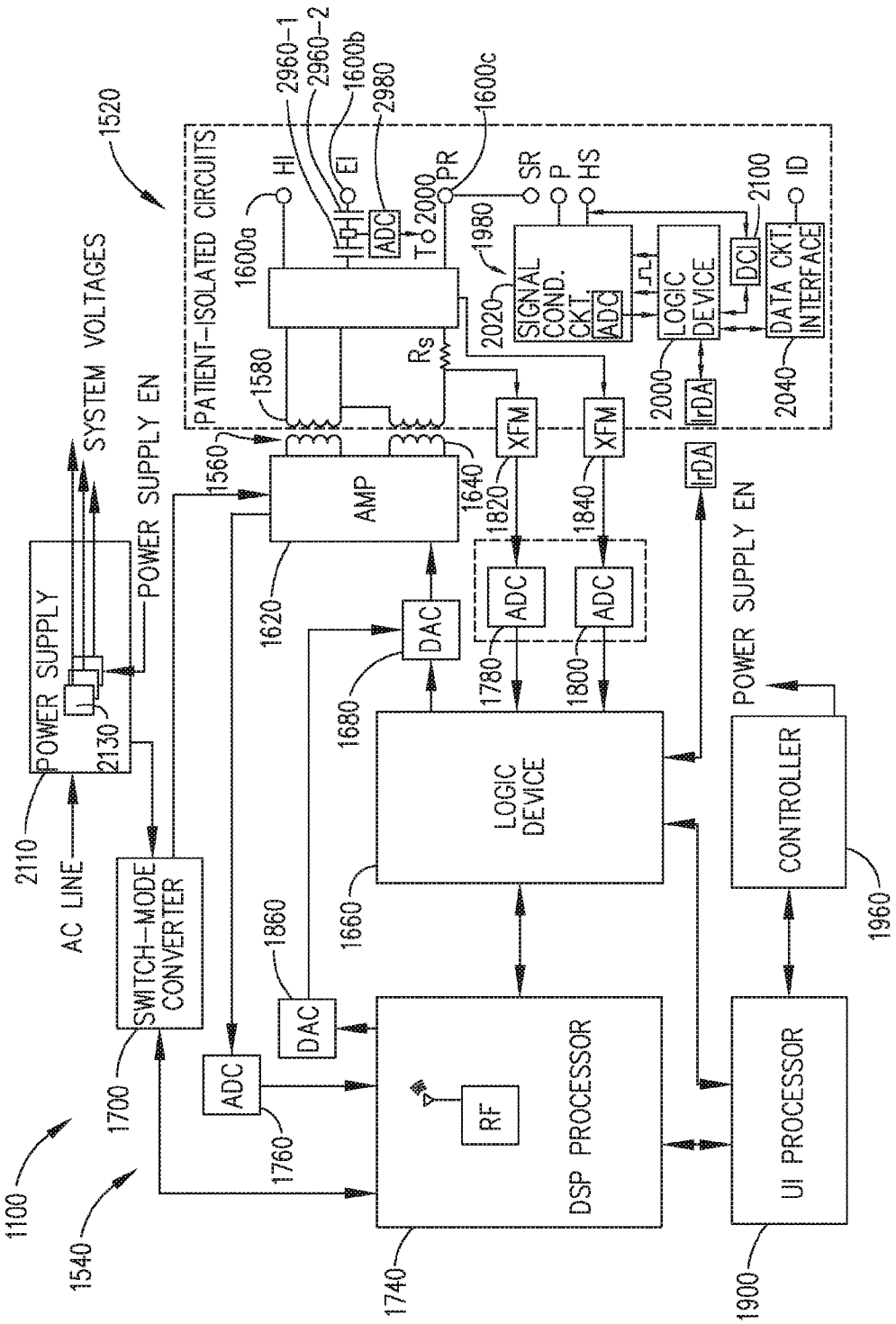

1520
PATIENT-ISOLATED CIRCUITS
2960-1
2960-2
1600b
2980
1600c
HI
EI
ADC
T
2000
PR
SR
P
HS
2100
ID
1600a
1980
SIGNAL COND. CKT.
ADC
LOGIC DEVICE
DCI
DATA CKT. INTERFACE
2020
Rs
1580
2000
IrDA
2040
XFM
XFM
1560
AMP
1640
1820
1840
IrDA
SYSTEM VOLTAGES
POWER SUPPLY EN
POWER SUPPLY
2130
2110
AC LINE
1620
DAC
ADC
ADC
1780
1800
1680
LOGIC DEVICE
POWER SUPPLY EN
CONTROLLER
1960
SWITCH-MODE CONVERTER
1700
1860
DAC
1660
ADC
1760
RF
DSP PROCESSOR
UI PROCESSOR
1100
1540
1740
1900

FIG. 20

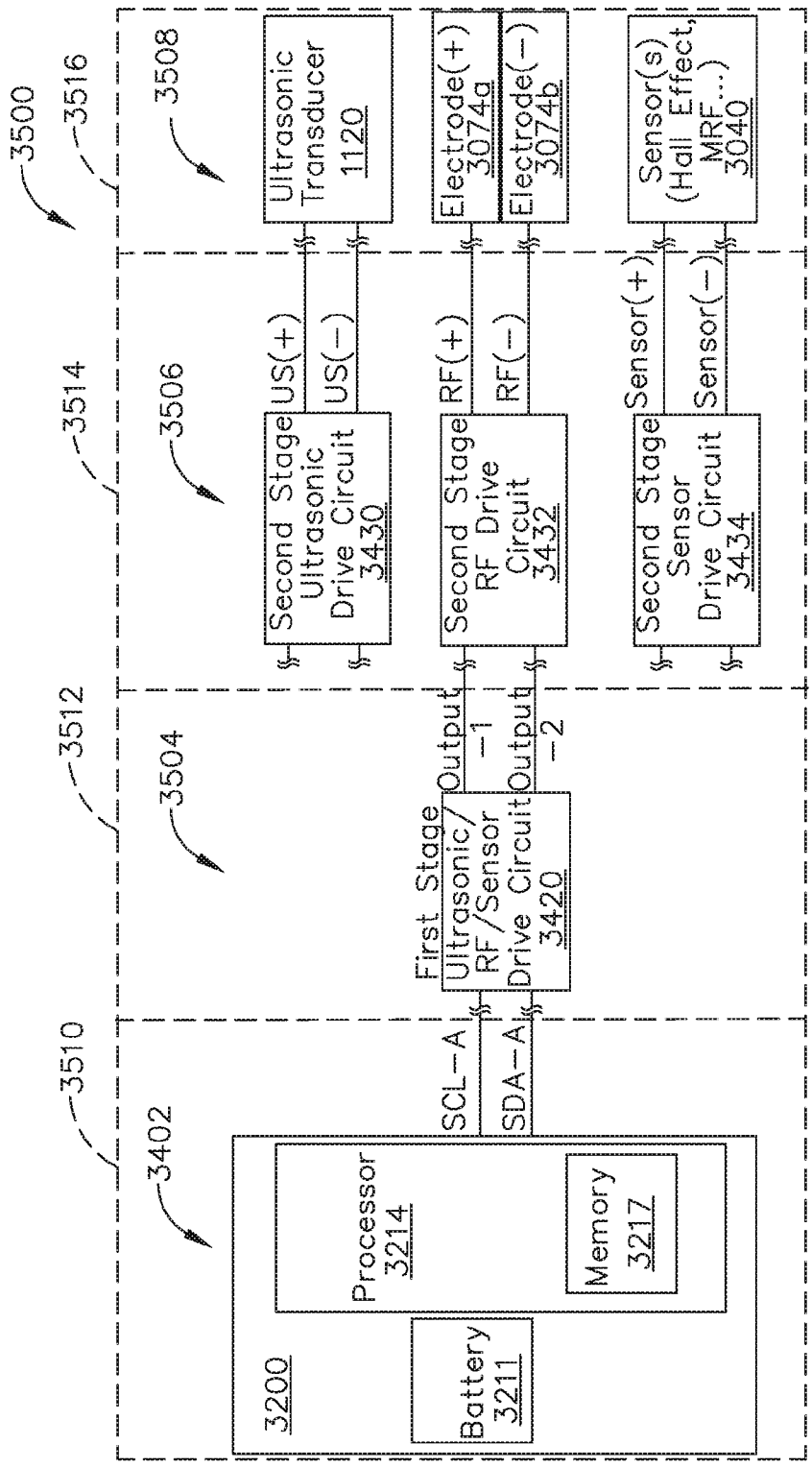

3500
3516
3508
3514
3506
3512
3504
3510
3402
3200
Battery 3211
Processor 3214
Memory 3217
SCL-A
SDA-A
First Stage Ultrasonic/ RF/Sensor Drive Circuit 3420
Output -1
Output -2
Second Stage Ultrasonic Drive Circuit 3430
Second Stage RF Drive Circuit 3432
Second Stage Sensor Drive Circuit 3434
US(+)
US(−)
RF(+)
RF(−)
Sensor(+)
Sensor(−)
Ultrasonic Transducer 1120
Electrode(+) 3074a
Electrode(−) 3074b
Sensor(s) (Hall Effect, MRF...) 3040

FIG. 21

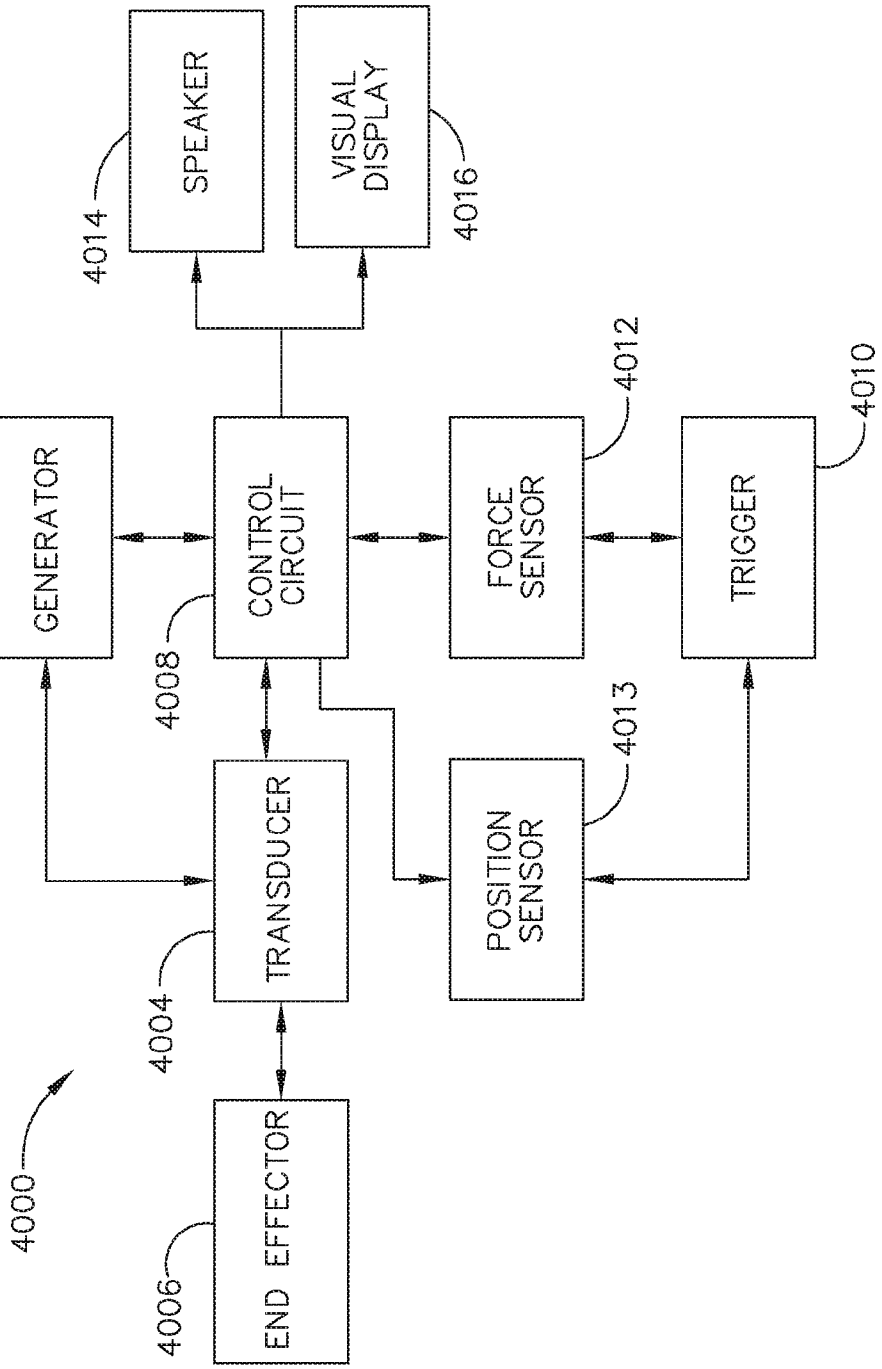

SPEAKER
VISUAL DISPLAY
4014
4016
4002
GENERATOR
CONTROL CIRCUIT
FORCE SENSOR
TRIGGER
4012
4010
4008
4013
TRANSDUCER
POSITION SENSOR
4004
4000
END EFFECTOR
4006

FIG. 22

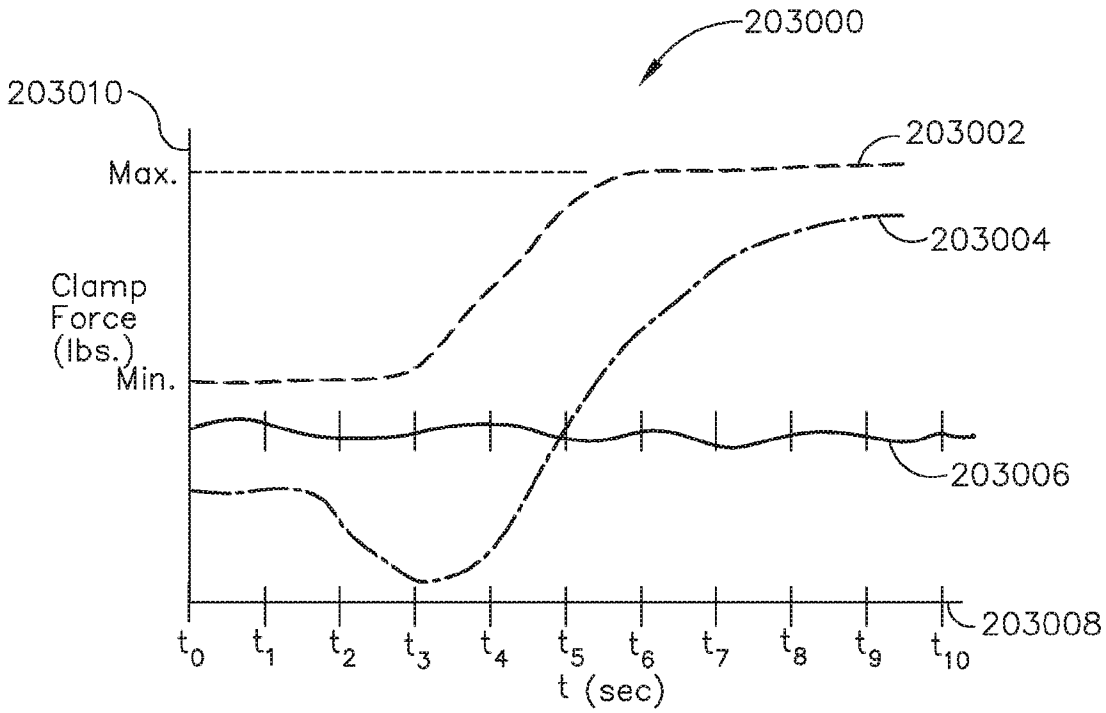

203000
203010
203002
Max.
203004
Clamp
Force
(lbs.)
Min.
203006
203008
t_0 t_1 t_2 t_3 t_4 t_5 t_6 t_7 t_8 t_9 t_{10}
t (sec)

FIG. 23A

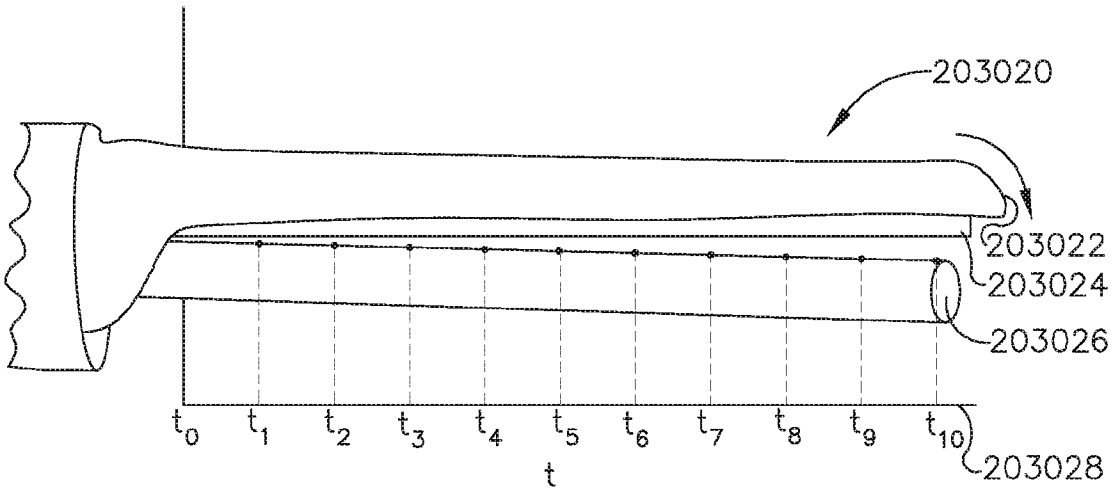

203020
203022
203024
203026
203028
t_0 t_1 t_2 t_3 t_4 t_5 t_6 t_7 t_8 t_9 t_{10}
t

FIG. 23B

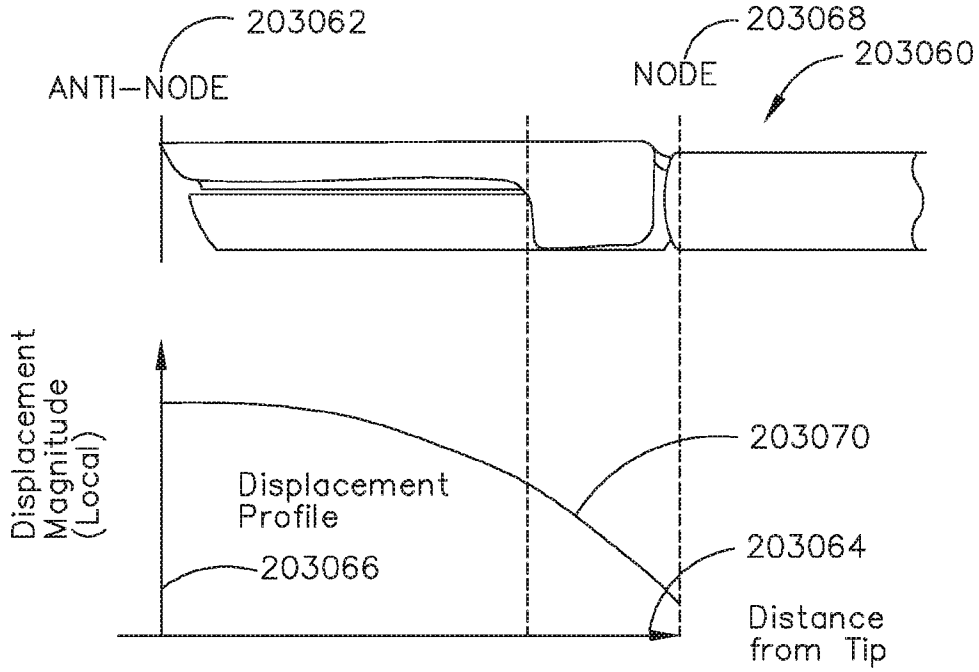


FIG. 24B

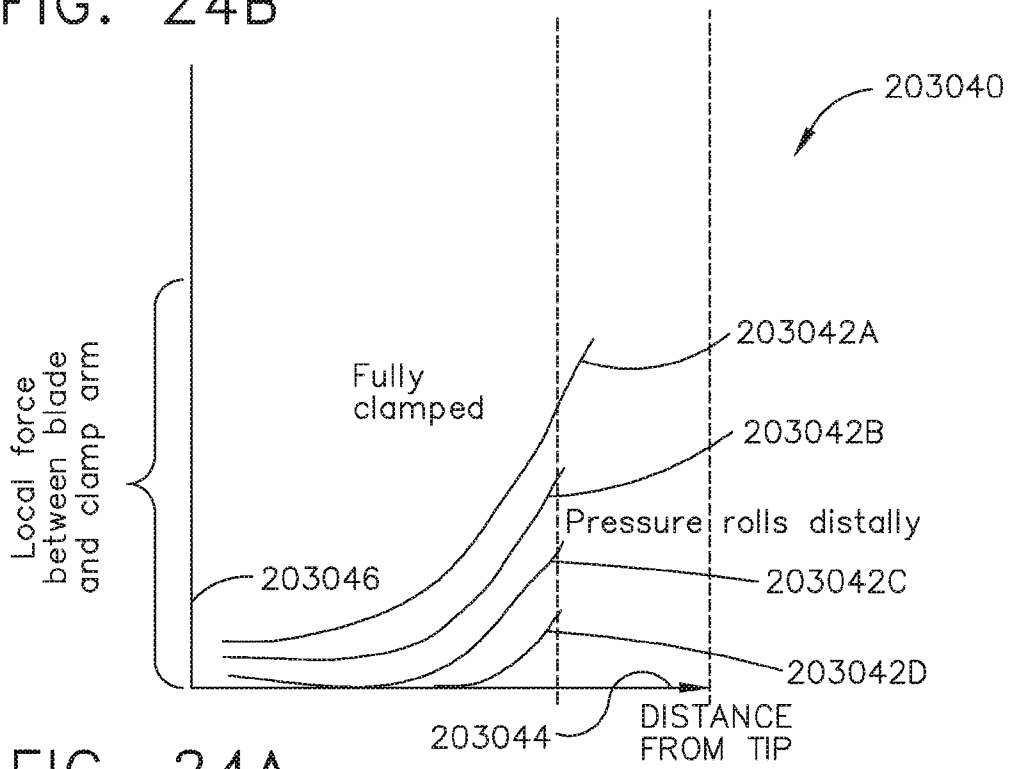


FIG. 24A

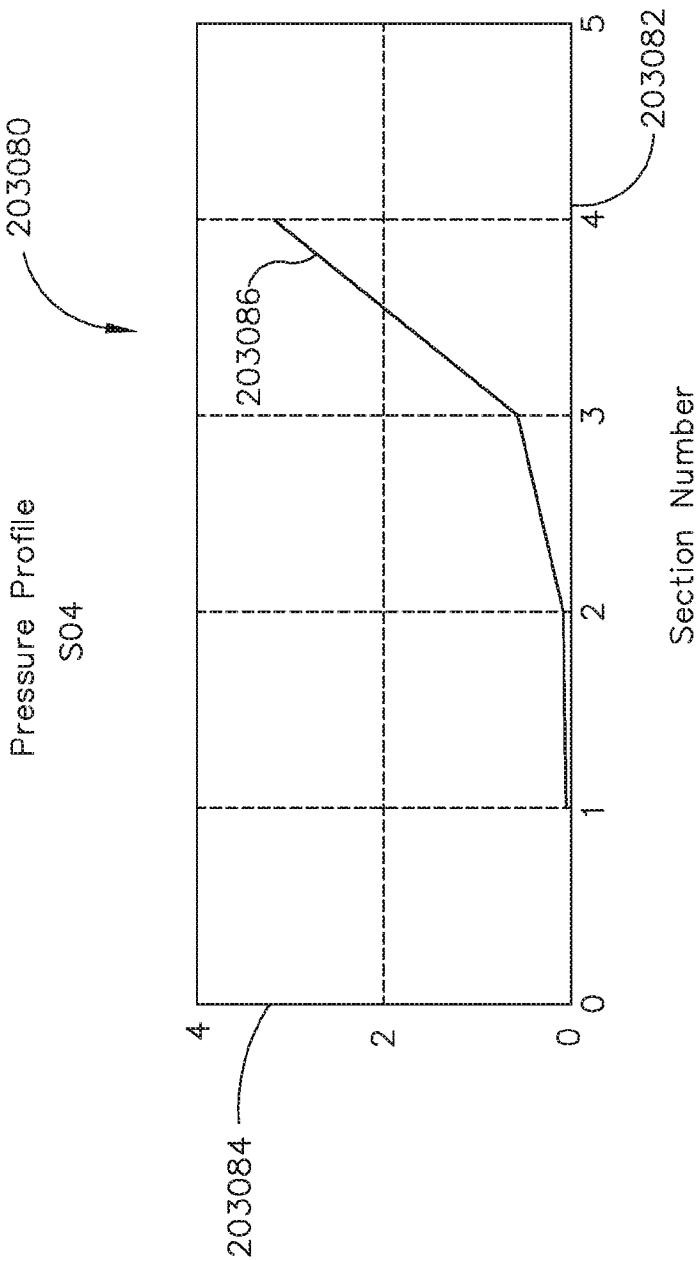

203080
Pressure Profile
S04
203086
203082
203084
Section Number
0
1
2
3
4
5
0
2
4

FIG. 25

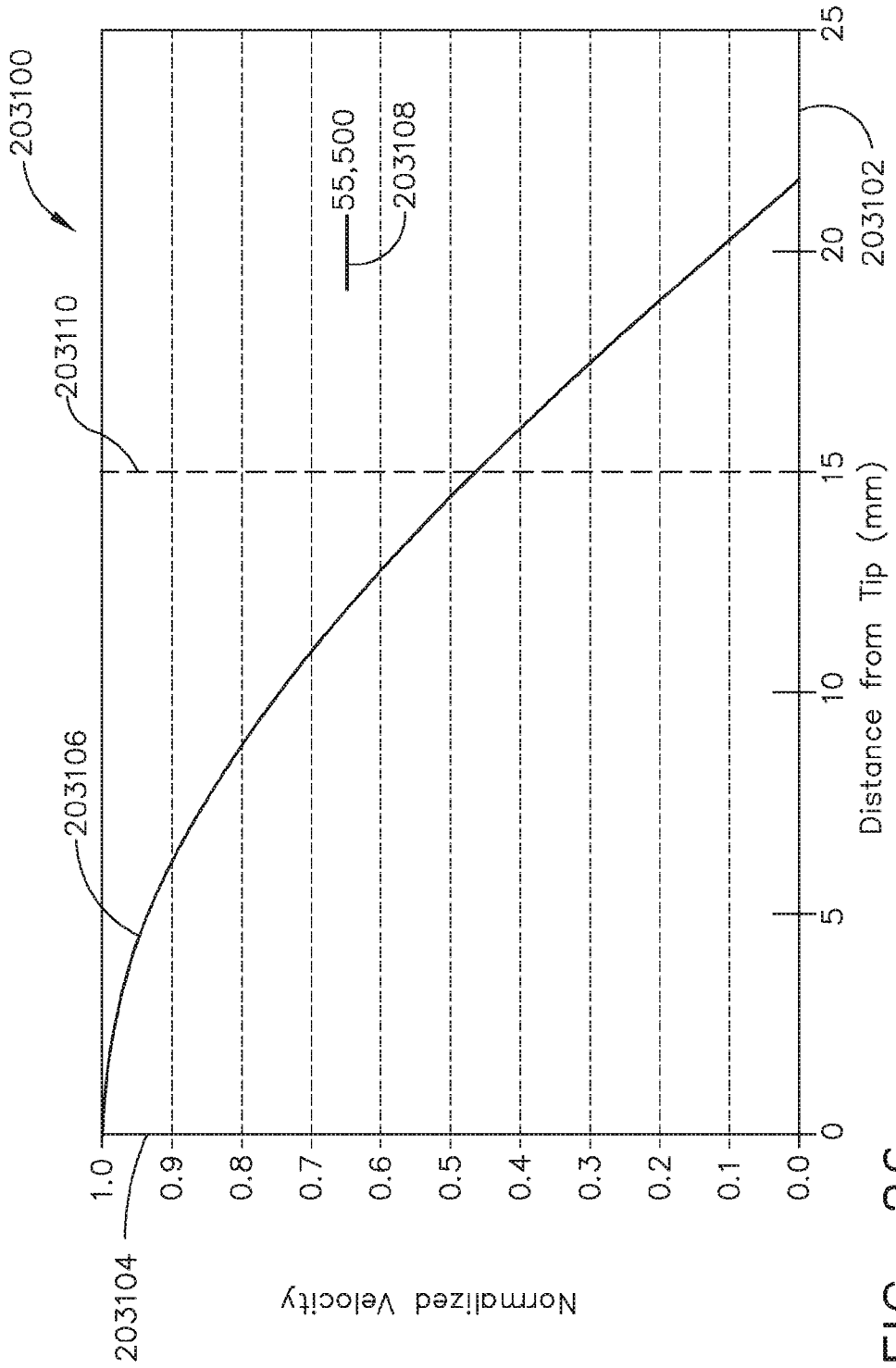

203100
203110
203106
203104
55,500
203108
203102
Normalized Velocity
Distance from Tip (mm)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25

FIG. 26

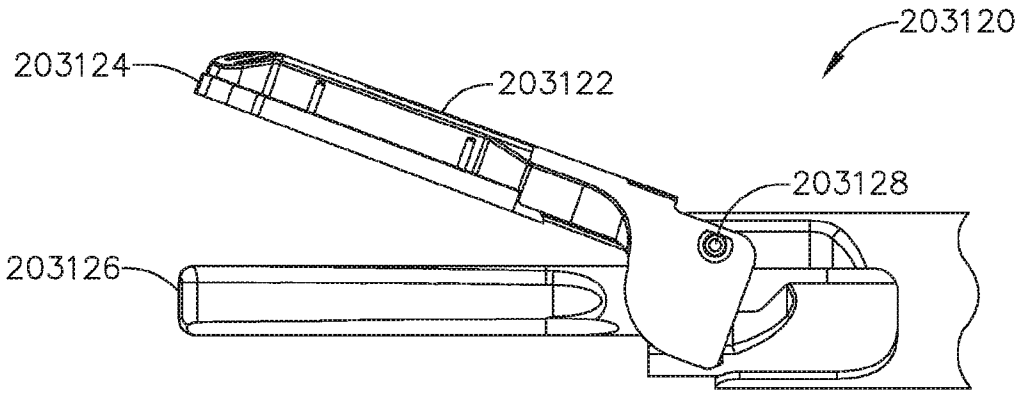


FIG. 27A

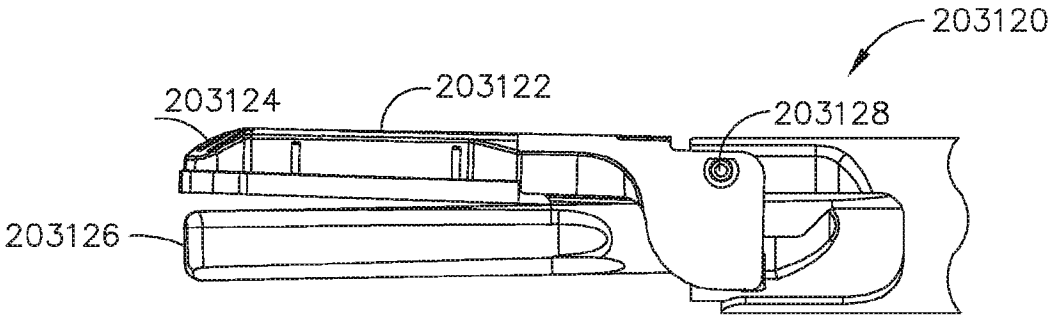


FIG. 27B

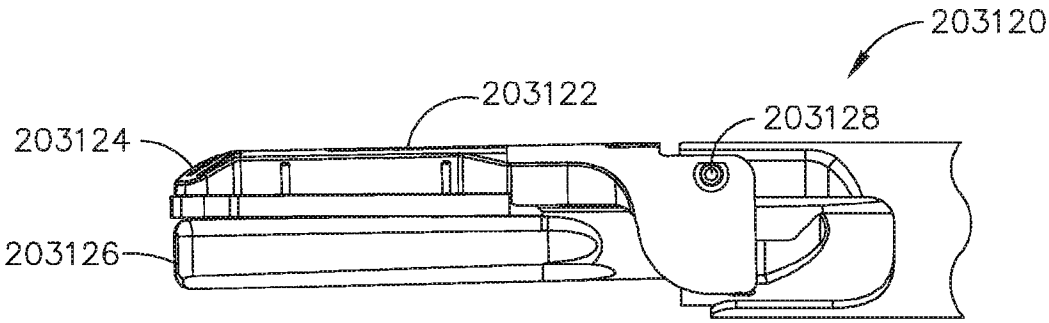


FIG. 27C

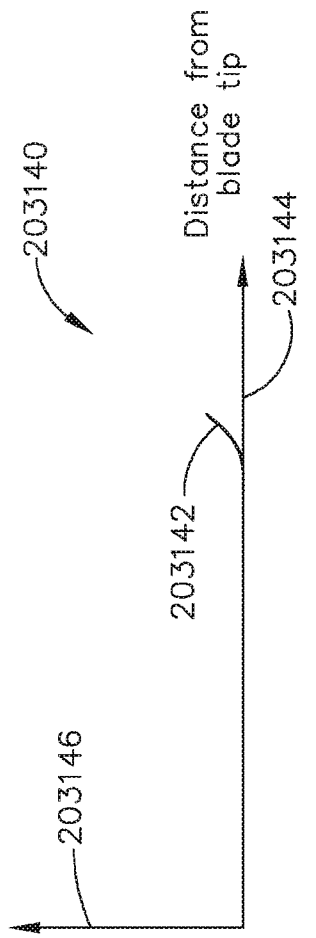


FIG. 28A

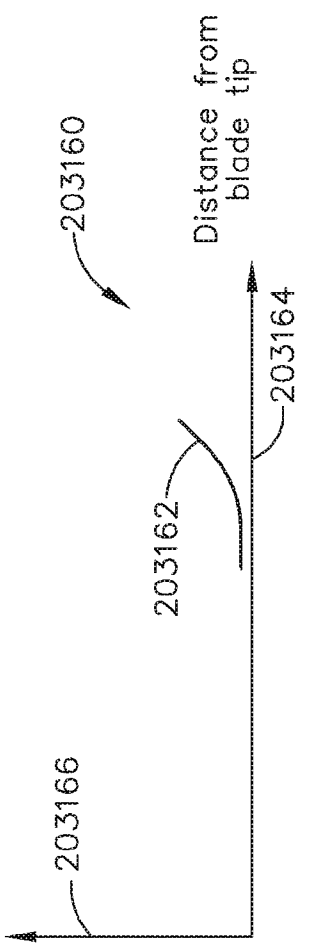


FIG. 28B

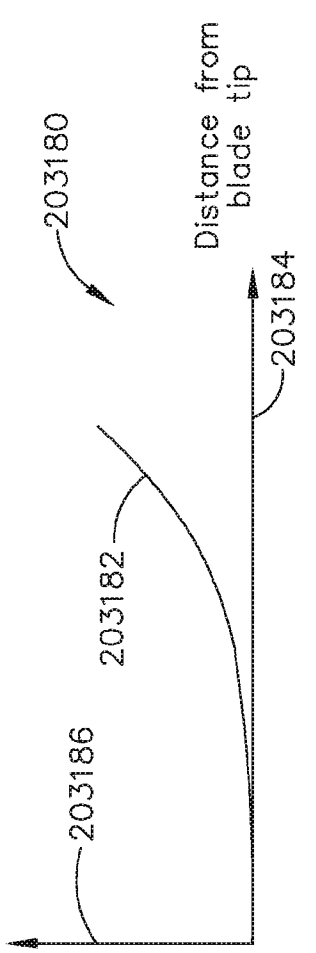


FIG. 28C

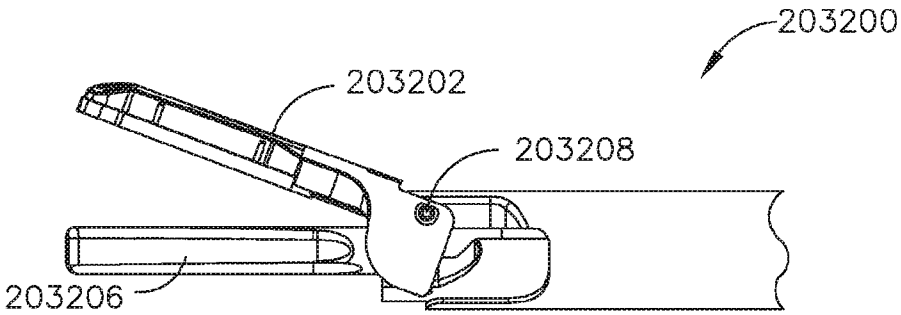


FIG. 29A

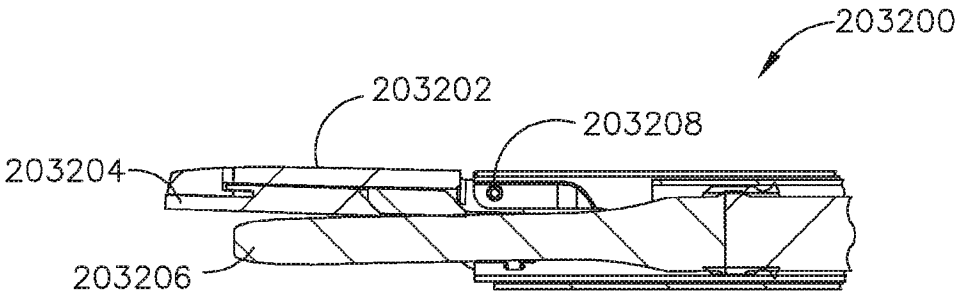


FIG. 29B

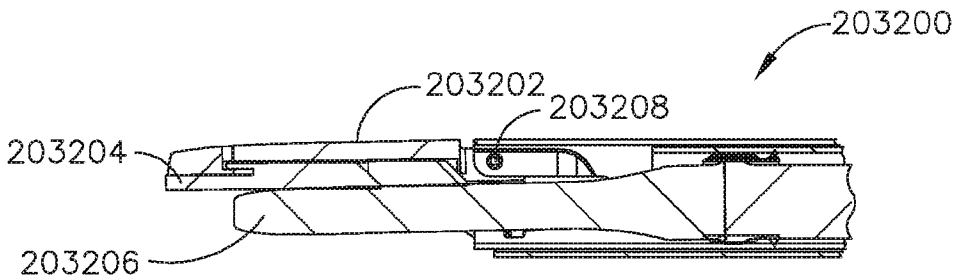


FIG. 29C

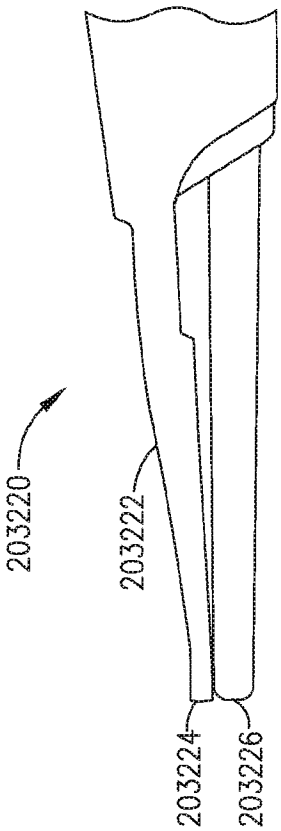


FIG. 30A

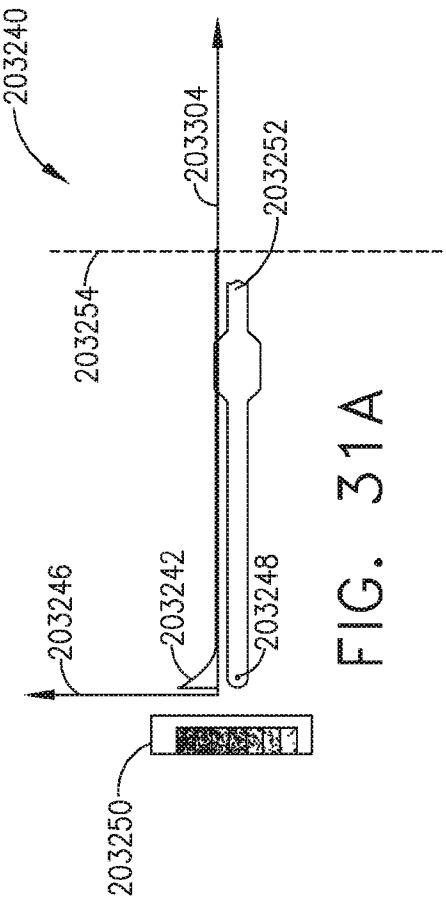


FIG. 31A

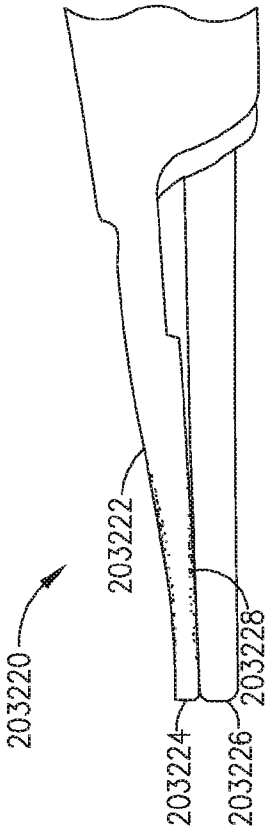


FIG. 30B

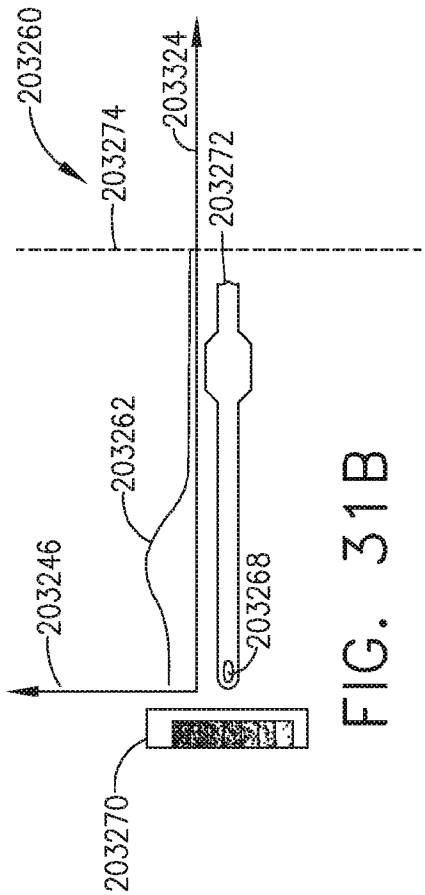


FIG. 31B

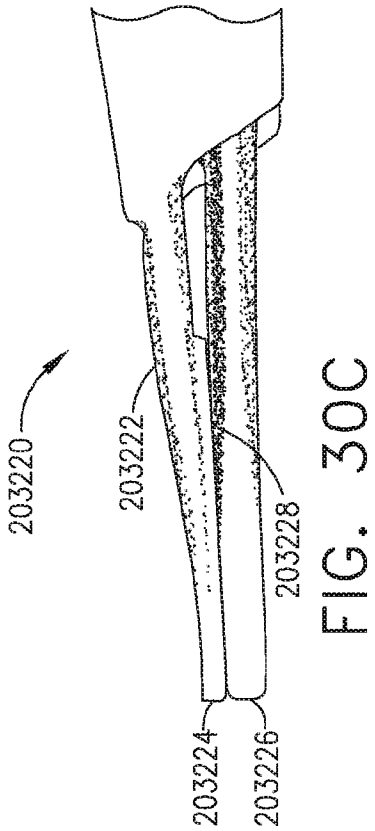


FIG. 30C

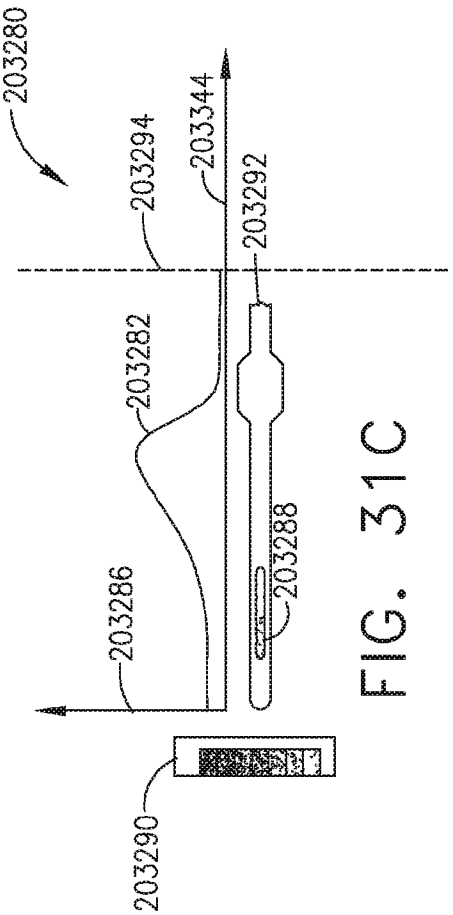


FIG. 31C

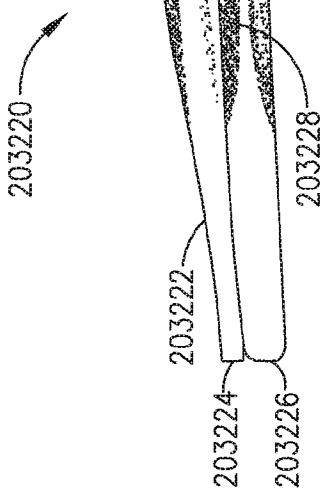


FIG. 30D

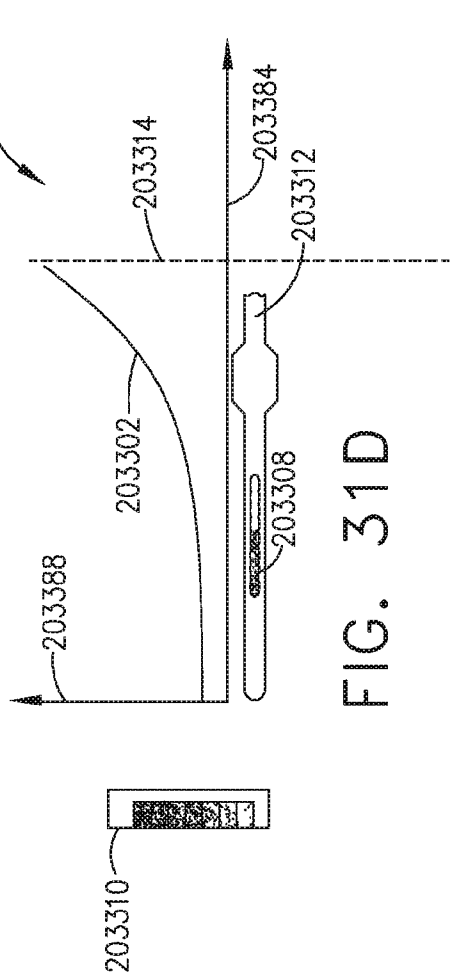


FIG. 31D

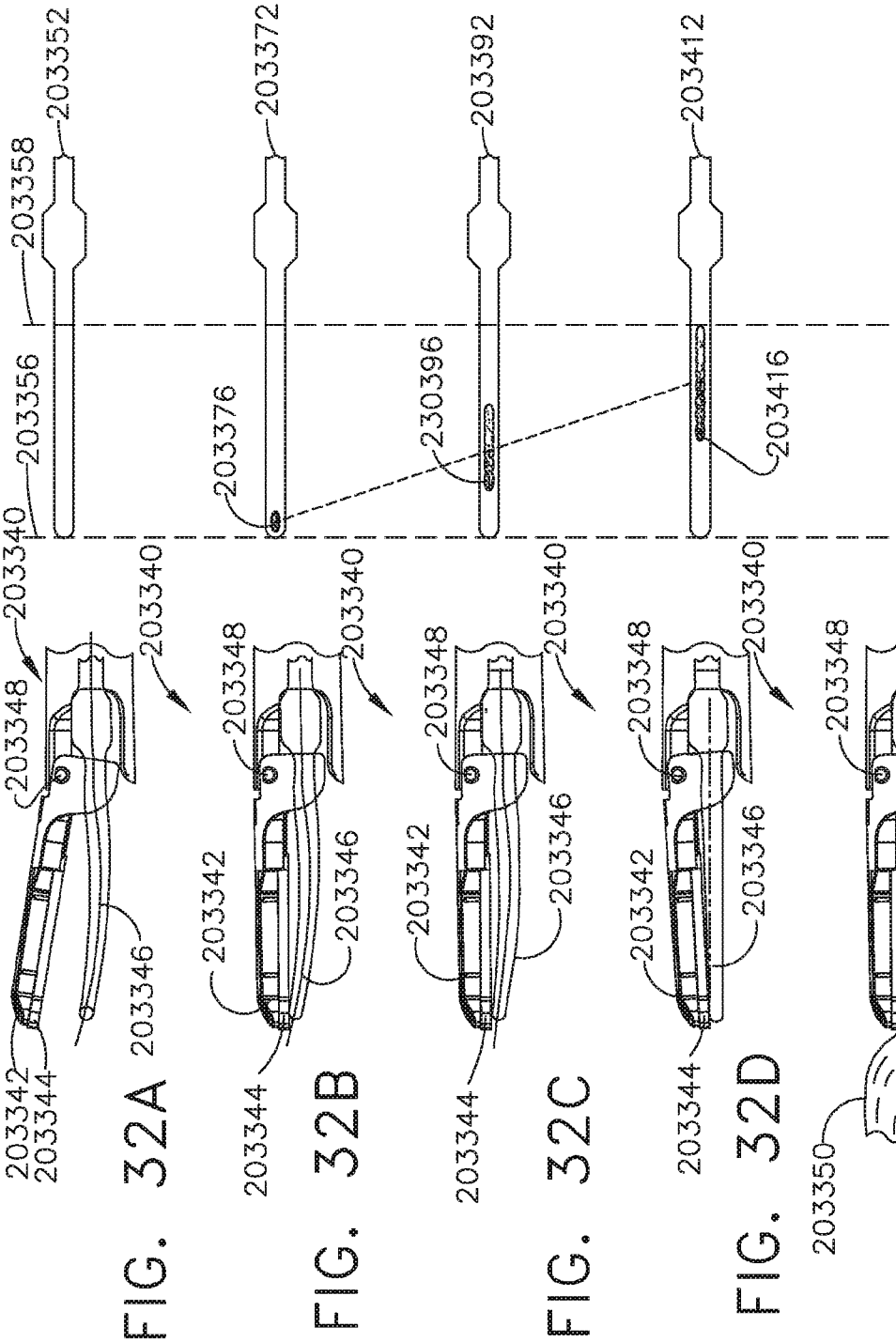


FIG. 32A

FIG. 32B

FIG. 32C

FIG. 32D

FIG. 32E

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/060981

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B17/32 A61B18/00 A61B17/00
ADD. B25J9/00 A61B50/18 A61B90/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B G16H B25J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2017/000516 A1 (STULEN FOSTER B [US] ET AL) 5 January 2017 (2017-01-05) abstract; figures 1-2, 20-22 paragraphs [0092], [0113], [0139], [0154], [0160] - [0162]	1-7, 15-20
A	EP 2 578 172 A2 (ETHICON ENDO SURGERY INC [US]) 10 April 2013 (2013-04-10) abstract; figures 1-3, 75 paragraphs [0005], [0267] - [0268]	1-7, 15-20
A	US 2017/238991 A1 (WORRELL BARRY C [US] ET AL) 24 August 2017 (2017-08-24) abstract; figures 1A-1B,88,93 paragraphs [0534], [0539] - [0540], [0587]	1-7, 15-20

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 February 2019	20/02/2019

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Macaire, Stéphane

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/060981

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2016/201123 A1 (INTUITIVE SURGICAL OPERATIONS [US]) 15 December 2016 (2016-12-15) abstract; figures 1,8 page 19, lines 2-15 -----	15-20

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/060981

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 8-14
because they relate to subject matter not required to be searched by this Authority, namely:

Pursuant to Article 17(2)(a)(i) and Rule 39.1 (iv) PCT, the subject-matter of claims 8-14 has not been searched, since it is directed to a method for treatment of the human body by surgery (using a surgical instrument, or closing a clamp arm on a tissue).

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2018/060981

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2017000516 A1	05-01-2017	BR 112017028462 A2	28-08-2018
		CN 107708592 A	16-02-2018
		EP 3316812 A1	09-05-2018
		JP 2018519914 A	26-07-2018
		US 2017000516 A1	05-01-2017
		WO 2017003852 A1	05-01-2017
EP 2578172 A2	10-04-2013	AU 2012227304 A1	18-04-2013
		CA 2791681 A1	03-04-2013
		CN 103027748 A	10-04-2013
		EP 2578172 A2	10-04-2013
		JP 2013078585 A	02-05-2013
US 2017238991 A1	24-08-2017	US 2017238991 A1	24-08-2017
		WO 2017146902 A1	31-08-2017
WO 2016201123 A1	15-12-2016	CN 107847283 A	27-03-2018
		EP 3307196 A1	18-04-2018
		JP 2018517506 A	05-07-2018
		KR 20180006939 A	19-01-2018
		US 2018153632 A1	07-06-2018
		WO 2016201123 A1	15-12-2016